THE JOURNAL OF THE ROYAL ASTRONOMICAL SOCIETY OF CANADA

DEVOTED TO THE ADVANCEMENT OF ASTRONOMY AND ALLIED SCIENCES

JUNE 1960

Vol. 54, No. 3 Whole No. 444

ANDREW McKELLAR

1910 - 1960

It is with deep regret that we announce the death of Dr. Andrew McKellar in Victoria, B.C. on May 6, 1960, in his second year as President of the Royal Astronomical Society of Canada. An obituary will appear in the next issue of the JOURNAL.

PRINTED IN CANADA
BY THE UNIVERSITY OF TORONTO PRESS

VIRTUAL MACHINES

XU

THE JOURNAL OF THE
ROYAL ASTRONOMICAL SOCIETY
OF CANADA

Vol. 54. No. 3 JUNE 1960 Whole No. 444

SOME TOPICS IN MOLECULAR ASTRONOMY*

By Andrew McKellar†
Dominion Astrophysical Observatory, Victoria, B.C.

Introduction. In the hotter regions of astronomical bodies such as in the atmospheres of the hotter stars and in all stellar interiors, matter exists in the form of atoms or parts of atoms. In cooler regions, however, such as in the atmospheres of stars with surface temperatures less than about 7000°K, it is cool enough so that two atoms, when they come close enough to join and form a molecule, do not necessarily have so much energy that they fly apart immediately. Thus a quantity of the material exists in the form of molecular compounds. Generally speaking, the lower the temperature the greater the amount of the material that exists as molecules. Examples of such molecules are those of CH and CN in the sun's atmosphere, CH, CN, C_2, TiO, ZrO, etc. in atmospheres of the cooler, redder stars, CH, CN, N_2^+, CO^+ in comets, CO_2 in the atmosphere of Venus, CH_4 and NH_3 in the atmospheres of the major planets and the familiar N_2, O_2 and H_2O in the earth's atmosphere.

The presence of molecules in distant bodies is made known to us through the use of the spectrograph. While matter in atomic form gives a pattern of line spectra, molecules generally give a pattern of bands, readily distinguished from atomic spectra. The bands, when examined by more powerful spectrographs, are broken up into characteristic series of lines. Examples of band spectra are shown in figure 1.

In this paper I will briefly discuss a few topics of recent and present interest to astronomers, involving the study of molecules in various classes of astronomical bodies.

*Parts of this paper constituted the Presidential Address delivered at the General Assembly of the Royal Astronomical Society of Canada in Montreal, April 8, 1960.

†Dr. Andrew McKellar died on May 6, 1960, shortly after his return from Montreal where this paper was presented—*Editors.*

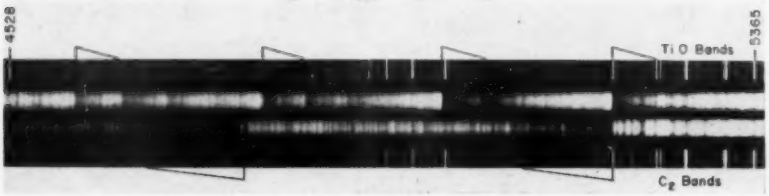


FIG. 1—*Above*: dark molecular absorption bands in the spectrum of an M-type star; *below*: an N-type star. The bands of TiO in the M-type spectrum are shaded toward longer wave-lengths (to the right) while the C_2 bands in the N-type spectrum are shaded to shorter wave-lengths.

The Atmosphere of Venus. The special interest in the planets Venus and Mars in the present dawn of space-vehicle activity is almost too obvious to require comment. It has been known since the work of Adams and Dunham (1932) on the near infrared spectrum, that the atmosphere of Venus contains a considerable amount of CO_2. It has not been possible to specify exactly the amount (Herzberg 1951) because of pressure and temperature differences between laboratory and planet and also because there is evidence the amount varies with time. There probably is present, however, at least several hundred metre-atmospheres.

In 1953, the Russian astronomer, N. A. Kozyrev (1954) made spectrographic observations of the dark part of Venus at its crescent phase, an experiment proposed by G. Herzberg in his 1951 paper in this JOURNAL, referred to above. Kozyrev's plates of the "night sky" of Venus revealed numerous molecular bands in emission. He measured over 50 bands between the near ultraviolet and yellow spectral regions (λ3500 to λ5700). Of these bands he identified two as the λ3914 and λ4278 bands of N_2^+, a number of others as members of the second positive system of N_2 and stated that the Vegard–Kaplan bands of N_2 were absent. Most bands were unidentified.

Kozyrev estimated that the brightness of the night sky of Venus was about 50 times greater than that of the earth's night sky. The question arises as to whether the glow in the night sky of Venus was of the nature of a normal Venusian air-glow or an auroral-like phenomenon. Kozyrev favoured the latter.

Recently G. Newkirk (1959) working at the High Altitude Observatory, Climax, Colorado, carried out some observations similar to those of Kozyrev, using a coronagraph-type optical system to cut down scattered light. He was not able to confirm the presence of all the emission bands listed by Kozyrev, but did confirm two of the stronger ones at 4415 A. and 4435 A.

If the glow is of an auroral type, it would be expected to vary in brightness from night to night, just as do our northern lights. Therefore it is possible that the results of Kozyrev and Newkirk can be reconciled. In this connection we find references throughout the literature over many decades to visual observation of an "ashen light" over the dark part of Venus, having been seen from time to time.

In addition to his work on the night sky of Venus, Kozyrev (1954, 1955, 1956) obtained spectra of the light reflected from the bright side of the planet and compared them with the spectrum of the sun. His measurements showed some general absorption increasing from the violet (λ4540) to shorter wave-lengths and showed also two red-degraded absorption bands with heads at $\lambda 4109 \pm 1$ and $\lambda 4382 \pm 1$.

He found, further, that these two bands were present in the spectra of the sun and of Vega when photographed at low altitudes near the horizon, and so concluded that the molecule responsible for them existed in the earth's atmosphere as well as in that of Venus. He estimated that the molecule was about six times more abundant in the atmosphere of Venus than in that of the earth. The molecule responsible for these bands has not been identified.

Subsequently, Urey and Brewer (1957) in commenting upon possible fluorescence effects in planetary atmospheres, discussed the molecular ions CO^+ and CO_2^+ in the atmosphere of Venus, and noted some general but not accurate or convincing coincidences between spectra of these molecules and Kozyrev's tables of emission bands and his two absorption bands. Still more recently, Heyden, Kiess and Kiess (1959) and E. H. Richardson (1959) have reported investigations of the spectrum of the light reflected from Venus. Both used considerably higher spectrographic power than Kozyrev, and neither found evidence of the absorption bands at $\lambda\lambda$4109 or 4382. A comparison of Richardson's and Kozyrev's results near λ4382 is shown in figure 2, where it is seen that Richardson's points show no band head at that wave-length. Richardson's work started at Victoria last year and is being continued. He plans not only to continue the study of the reflection spectrum of Venus but also to try to obtain spectra of the planet's night sky.

If the results of the several sets of observations described above are correct, the most obvious way in which they can be reconciled is to suppose that not only the spectrum of the Venusian night sky but also that of its reflected light varies to some extent with time. If so, it would appear important to make frequent observations and to pursue the problems of identification of the spectral features found. One way in which observations by amateur astronomers with sufficiently good telescopes

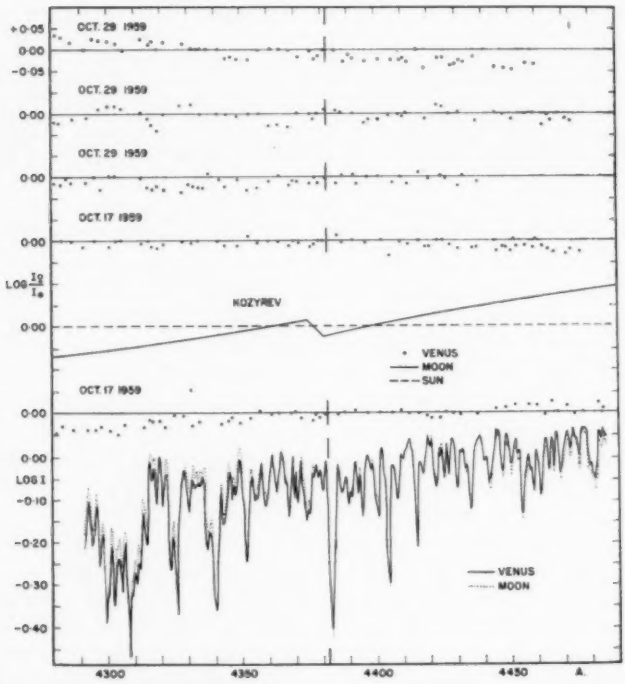


FIG. 2—This illustrates the results of E. H. Richardson's measurements on the spectrum of Venus near the λ4382 region of Kozyrev's reported absorption band. Note that Richardson's spectra of October 1959, do not reveal any absorption band of appreciable strength.

might be of value would be in recording any occurrences of the so called "ashen light" over the dark part of Venus.

Bands of CN *in Cometary Spectra and of* N_2^+ *in Spectra of Sunlit Aurorae.* Nearly two decades ago, the peculiar intensity distribution within the emission bands of CN long known in the spectra of comets was explained by P. Swings (1941). He pointed out that if the emission takes place as the result of absorbing and re-emitting solar radiation (fluorescence), the fact that, as shown by the occurrence of the multitude of absorption lines in the solar spectrum, the exciting solar radiation has a very uneven intensity distribution, would result in an uneven distribution within the emission bands. Through work done at Victoria and elsewhere, Swings'

explanation was quantitatively confirmed, thus proving that the cometary bands were indeed produced by a process of fluorescence.

Comparatively recently two interesting developments in this field have occurred. First, J. L. Greenstein (1958) with the 200-inch telescope, has obtained and described spectrograms of Comet Mrkos (1957d) with much greater spectral resolution than had previously been used. The CN band at λ3883 from these plates has been further discussed by Hunaerts (1959). On the well resolved band, not only are the previously known variations of intensity from line to line better shown than ever before but another interesting effect is present. At the two extremities of the spectral lines, corresponding to points in the comet's head about 10,000 km. east and west, respectively, of the central nucleus, the relative intensities of various individual lines in the R branch of the band differed appreciably. These differences can be ascribed to radial components of motion outward from the cometary nucleus. These components, of less than 3 km./sec., effectively shift the solar spectrum slightly in wave-length, as seen by the cometary molecules concerned, and since the sides of solar absorption lines are steep, change the amount of radiation received at a particular wave-length. Hence there is a change in the populations of upper rotational states of CN and a consequent difference in intensities of the emission lines at the two opposite parts of the cometary head. Hunaerts favours rotation of the cometary head, rather than radial or random motions, as the source of the relative velocities in different parts of the cometary head.

The second development concerns the spectra of the very high sunlit aurorae. Sometimes aurorae occur so high that, while the observer on the earth's surface is in darkness, the high atmosphere is still illuminated by the sun. It was suggested some time ago that possibly the N_2^+ molecular emission bands in the spectra of such aurorae might be excited through fluorescence by the sunlight, but no spectrograms of sufficient resolution were available to detect the expected irregular intensity distribution. Spectra obtained of a high sunlit aurora in September 1958 at the University of Saskatchewan (Hunten, Koenig and Vallance Jones 1959; Vallance Jones and Hunten 1960) have shown the λ3914 band with sufficient resolution to measure its irregular profile. From the measurements it is found that the band profile is consistent with fluorescent excitation from a state of thermal equilibrium at 2200°K. and also that the distribution of intensity from band to band gives a "vibrational" temperature of about 2050°K. Thus the evidence is that the behaviour of the molecules at a height of 400 to 500 km. in the atmosphere indicate a temperature of a little over 2000°K.

Interstellar Lines. The spectra of distant stars show absorption features which are attributable to absorption by interstellar material. There are about 30 very sharp interstellar lines known. These are all identified as arising from neutral and singly ionized atoms and diatomic molecules, NaI, CaI, II, FeI, KI, TiII, CH, CH^+, and CN. In addition to these lines, there is a group of 10 diffuse interstellar absorption features. Eight of these were discovered by Merrill and by Merrill and O. C. Wilson at the Mount Wilson Observatory in the mid-1930's, (see, for example, Merrill and O. C. Wilson 1938). The other two were recently added by R. Wilson (1958) while at Victoria. The wave-lengths and characteristics of these diffuse features are as shown in the table.

THE DIFFUSE INTERSTELLAR LINES

Wave-length	Number of plates	Estimated relative intensity on arbitrary scale	Width	Central absorption	Discoverer
6613.9±0.01	39	2			P. W. Merrill (1934)
6283.91±0.03	219	6	7–12 A	4–23%	P. W. Merrill (1934)
6269.99±0.04	14	1			P. W. Merrill and O. C. Wilson (1938)
6202.99±0.06	9	1–			P. W. Merrill and O. C. Wilson (1938)
5797.13±0.04	141	1	2.5– 4 A	3–11%	P. W. Merrill (1934)
5780.55±0.03	229	3	4– 8 A	5–25%	P. W. Merrill (1934)
6180			50–60 A	5%	R. Wilson (1958)
4890			40–50 A	5%	R. Wilson (1958)
4760			50 A	5%	P. W. Merrill, verified by Robert Wilson
4430.6			150 A	15%	P. W. Merrill

Not one of these diffuse interstellar lines has been identified. They fall into two groups. The upper 6 features listed in the table have widths of only a few angstrom units and appear visually on the spectrograms as diffuse lines. The lower 4 features are much wider and, except for λ4430 for a few cases, show only on microphotometer tracings of the spectra.

The interstellar material contains not only free atoms and molecules, but also the dust particles and grains that cause interstellar reddening

of starlight. Studies have indicated that the intensities of at least the upper group of six diffuse interstellar lines show a better correlation with interstellar reddening than with the intensities of the sharp interstellar lines. It is therefore concluded that the source of the diffuse interstellar lines is probably associated with the interstellar grains. These grains are at very low temperatures, at most of the order of 50 or 60°K. Could the lines arise from atoms or molecules condensed on the surface of these cold grains, much in the manner of the atoms and radicals that are the object of experimental investigation by Broida and others?

Some years ago we noticed that two or three of the bands fall in the region of absorption bands of solid oxygen, and some experiments were made by McKellar, Welsh and Stephenson (1955), with no conclusive results as regards identification. The wave-length coincidences were suggestive but not exact. Other work along this line has been reported by Bass and Broida.

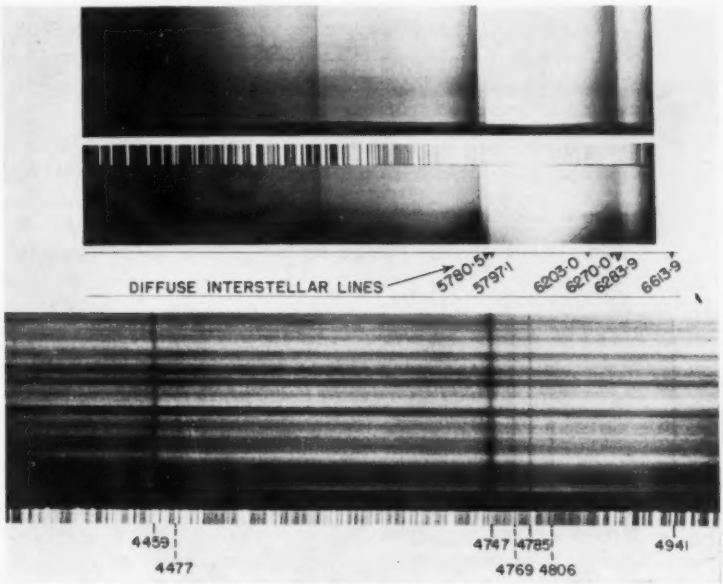


FIG. 3—*Top section*: spectrum of solid oxygen in the yellow and red regions, photographed by McKellar, Welsh and Stephenson. Positions and relative intensities of a number of diffuse interstellar lines are indicated. The additional shifted band heads in the lower parts of the spectra show the effect of solidification into two of the different (α and β) crystal structures of solid oxygen. *Bottom section*: spectrum of solid oxygen in the blue-violet region where the absorption bands are seen to have a diffuse character similar to the interstellar lines.

Part of the reason that no conclusive results were possible was that the strong bands of solid O_2 differed by small amounts in wave-length from the interstellar lines near λλ6284, 6270, 5770, 5797 and 4760. A photograph of the bands of solid oxygen is shown in figure 3, where positions of the interstellar lines are also marked. H. P. Broida in a paper given at the symposium on molecular spectroscopy at Columbus, Ohio, June 1959, stated among other things, that varying wave-length shifts occur in the spectra of molecules trapped at very low temperatures, depending upon the different matrices in which the molecules are condensed. Does this mean that O_2 is still a possible identification for some of the diffuse interstellar lines? I do not know. The answer will probably have to await further laboratory work, possibly of the type being done by Broida and his collaborators, where atoms and molecules are condensed on surfaces at very low temperatures. (See, for example, Bass and Broida 1956; Peyron and Broida 1959; Peyron, Horl, Brown and Broida 1959.)

We astronomers would be grateful if the physicists doing work on the spectra of simple molecules and radicals at very low temperatures would keep in mind the interesting problem of the identification of the diffuse interstellar lines.

The Cool Carbon Stars. The cool carbon stars are a fairly small group (several hundred known) having temperatures ranging from about that of the sun down to those of the coolest visible stars (~1500°K.). Their spectra are characterized by the presence in considerable strength of absorption bands of C_2, CN and CH, and they are designated as spectral types R and N, or C. There are reasons for believing that the atmospheres of these stars contain considerably more carbon than do those of other stars. There are three topics concerning these stars that I should like to mention.

1. *The Source of Opacity in the Violet and Ultraviolet.* For the hottest of the cool carbon stars, namely those of early R-type or early C-type, one can obtain spectrograms down to the limit of transmission of the earth's atmosphere. For the coolest carbon stars, however, those of late R or late N-types, the decrease in radiation from λ5000 to λ4000 or λ3500 is unbelievably extreme, much too great to be accounted for by the low temperature. To give an illustration, while the region at λ4800 can be photographed in a few seconds, exposures of several hours can scarcely extend the spectrum beyond λ3900.

There were reasons for believing the opacity to be of molecular origin and a first promising clue to the identity of at least one possible agent

followed the discovery of the λ4050 system of C_3 bands in the spectra of some late N-type stars. Phillips and Brewer (1955) found, when the C_3 bands were produced by an electric furnace, that they were accompanied by a continuum. The continuum extended well into the ultraviolet; it had a main maximum around 4000 A. and secondary maximum near 4300 A. Phillips and Brewer and later Marr and Nicholls (1955), using an oxy-acetylene flame as a source, put forward good evidence that the continuum also arose from C_3. E. H. Richardson and I (McKellar and Richardson 1955) made some spectrophotometric measurements on the spectra of a number of cool carbon stars and found a definite resemblance between the profiles of the strong violet absorption in the spectra of the late N-type stars and Phillips and Brewer's C_2 continuum. We concluded therefore, that C_3 probably played some part at least in producing the violet opacity in the cooler carbon stars.

There remains one facet to this problem that should be further investigated and to which I should like to draw your attention. The complex system of Merrill–Sanford blue-green bands (λ4977, etc.), found in the atmospheres of the cooler N-type stars, were produced in the National Research Council laboratory at Ottawa by B. Kleman (1956) and shown to be probably due to the SiC_2 molecule, an analogue of the C_3 molecule. Swings, McKellar and Rao (1953) in a study of the violet region of N-type spectra had found that for the star U Hydrae, the Merrill-Sanford bands were sometimes present and sometimes absent. When the bands were present the very strong violet and ultraviolet absorption was present; when the bands were absent, the stellar spectrum did not show the extreme violet cut-off. It was therefore concluded that a connection probably existed between the presence of the molecule responsible for the Merrill–Sanford bands and the strong violet absorption. When SiC_2 molecules form in a stellar atmosphere, probably C_3 molecules also do. Thus the λ4050 C_3 bands and its associated continuum probably makes a contribution to the far violet opacity under these circumstances. But also, as Kleman pointed out, there is associated with the SiC_2 bands as produced in the electric furnace, a strong and extensive continuum. Is it not possible, therefore, that such a "SiC_2 continuum" also contributes to the violet opacity of late N-type stellar atmospheres and that this opacity therefore owes its existence both to C_3 and SiC_2? This is a question we should like to answer, but we cannot do so until more laboratory work is done on the SiC_2 bands and its continuum.

I would suggest that further laboratory studies should be done on SiC_2. There is need for work leading to the definite identification of SiC_2 as the emitter (possibly using for this purpose the isotopic effect), work

giving a detailed analysis of the system and work on the strength and profile of the associated continuum.

In this connection reference should perhaps be made to the new infrared band system discovered recently at Ottawa by Ballik and Ramsay (1958) using a King-type electric furnace containing silicon. This is the same source that Kleman used for his SiC_2 bands. The new bands lie between λ19,600 and λ22,700. Ballik and Ramsay state that these bands have a simpler rotational structure than Kleman's system. If the two systems are studied together, work on the one might aid in the analysis of the other.

2. *The* C^{12}/C^{13} *Isotopic Abundance Ratio in the Cool Carbon Stars.* A number of years ago in a study of the main and isotopic 1,0 bands of the C_2 Swan System near λ4740, it was found that there were apparently two main groups among the R-type stars (McKellar 1948). One group, 3 out of 21, showed no appreciable evidence of absorption bands involving C^{13}, and measurements indicated a C^{12}/C^{13} ratio of 50 or over. The terrestrial value is 90. The more numerous group, 12 out of 21, showed $C^{12}C^{13}$ and $C^{13}C^{13}$ bands from which it was deduced that the C^{12} to C^{13} ratio was fairly constant with a mean value of 3.4. (The remaining 6 stars had bands so strong that reliable results could not be obtained.)

In obtaining the above results it was assumed, for bands of weak to moderate strength, that the equivalent width of a band was proportional to the number of absorbing molecules. This point required looking into, and this has recently been done by J. L. Climenhaga (1960). He has calculated the profiles of a section of the 1,0 Swan band for various relative numbers of absorbing molecules and so has derived a curve of growth. When the curve of growth is used in evaluating the abundance ratio of C^{12}/C^{13} from the measured intensities in the R-type spectra, the previous mean value of 3.4 is increased to 5.8. A more detailed investigation of high-dispersion spectrograms of two of the R-type stars gives $C^{12}/C^{13} = 4.7$. In round numbers, the results of Climenhaga indicate a mean value about 5 instead of 3.5 for this group of R-type stars. For two stars of the smaller group showing little C^{13}, he refined the estimate of the abundance ratio to about 100 or more.

In addition to the above-mentioned work on the isotopic carbon bands of C_2 in the λ4740 blue spectral region, investigations have been made by A. Wyller (1957, 1958, 1960) of the λ6191 0,2 sequence of C_2 bands and of the λ6214 4,0 and λ7874 2,0 red CN bands. Wyller has used excellent high-dispersion data from the Mount Wilson Observatory, and has studied about six stars, mostly of type N. In his first paper (1957)

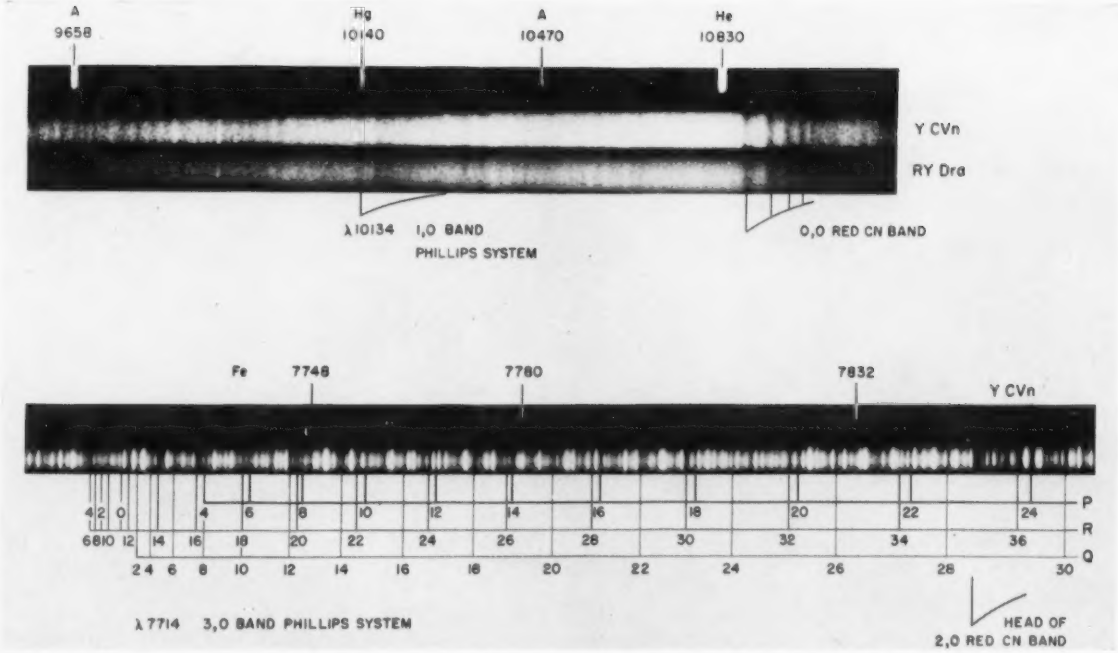


FIG. 4—*Above*: low dispersion spectra of the two cool carbon stars Y CVn and RY Dra; *below*: high dispersion spectrum of Y CVn. In the upper part the shading that probably corresponds to the 1,0 band of the Phillips singlet system of C_2 is seen while in the lower part the lines of the well-resolved 3,0 band of the Phillips system with head at λ7714, are indicated.

the estimates of the C^{12} to C^{13} abundance from the red C_2 bands, were low, ranging from about 1 to about 4. From the more recent studies, embracing also the red CN bands and using still better observational material, Wyller (1958, 1960) has obtained higher abundance ratios C^{12}/C^{13}, the values to which he gives most weight being about 9 or more.

Wyller has suggested that possibly errors involving blends with atomic lines, or photometric difficulties in determining the continuous spectrum or serious saturation effects in the strong bands, could have led to the low values obtained for some stars from the λ4740 C_2 bands. The differences between the results on the carbon isotopic ratio are indeed disturbing, and require further investigation, preferably in the near infrared spectral region. In view of the possible nucleogenetic importance of knowledge of the stellar C^{12}/C^{13} ratio, it is hoped that the further work of Wyller and that to be done at Victoria will bring satisfactory answers to the problem.

3. *Singlet Bands of* C_2 *in the Spectra of the Cool Carbon Stars.* It has generally been assumed that for the gaseous C_2 molecule the normal state is the lowest triplet state which is the lower state involved in the Swan band system. Among the supposedly good reasons supporting this conclusion were the great strength of the Swan system of C_2 in absorption in the carbon stars and the occurrence of the Swan bands, presumably by fluorescence, in cometary spectra. A recent investigation by Ballik and Ramsay (1959) in Ottawa has shown, however, without much doubt, that the lowest singlet state of C_2 lies about 610 $cm.^{-1}$ (0.075 e.v.) below the lowest triplet level and is therefore the ground state. Hence, bands arising from this lowest singlet state should be present in absorption in the spectra of the cool carbon stars.

Of the singlet systems of C_2, the one most favourably placed for astronomical observation is the Phillips system which occurs in the near infrared. A recent search on Victoria plates of the stars Y CVn (N3) and RY Dra (Np) has shown the Phillips bands to be present (McKellar 1960). On a grating spectrogram (dispersion 7.2 A./mm.) of Y CVn, the 3,0 band, degraded to longer wave-lengths from its head at λ7714.6, is present and well resolved into its individual lines. On low dispersion three prism plates (133 A./mm. at λ10,000) the 1,0 band with head at λ10,134 is seen shaded toward longer wave-lengths. These bands are shown in figure 4.

The presence of the Phillips bands is not only of interest in itself, but also for the further avenue of attack provided on the problem of the C^{12}/C^{13} isotopic ratio discussed above. The simple and open structure of

these bands is advantageous for the investigation of the corresponding bands involving the C^{13} isotope of carbon. This subject is presently under study at Victoria.

References

Adams, W. S. and Dunham, T. 1932, *P.A.S.P.*, vol. 44, p. 423.

Ballik, E. A. and Ramsay, D. A. 1958, *J. Chem. Phys.*, vol. 29, p. 1418.

Ballik, E. A. and Ramsay, D. A. 1959, *J. Chem. Phys.*, vol. 31, p. 1128.

Bass, A. M. and Broida, H. P. 1956, *Phys. Rev.*, vol. 101, p. 1740.

Burbidge, E. M., Burbidge, G. R., Fowler, W. A. and Hoyle, F. 1957, *Rev. Mod. Phys.*, vol. 29, p. 547.

Climenhaga, J. L. 1960, Paper presented at the Cleveland Meeting of the Am. Astron. Soc. Cleveland, December, 1959, *A.J.* (in press); *P. Dom. Ap. O.*, vol. 11, no. 16 (in press).

Greenstein, J. L. 1958, *Ap. J.*, vol. 128, p. 106.

Herzberg, G. 1951, *J.R.A.S. Can.*, vol. 45, p. 100.

Heyden, F. J., Kiess, C. C. and Kiess, H. A. 1959, *Science*, vol. 130, p. 1195.

Hunaerts, J. 1959, *Ann. d'Ap.*, vol. 22, p. 790.

Hunten, D. M., Koenig, H. J. and Jones, A. Vallance. 1959, *Nature*, vol. 183, p. 453.

Kozyrev, N. A. 1954, *Pub. Crimean O.*, vol. 12, p. 169 and p. 177.

Kozyrev, N. A. 1955, *Pub. Crimean O.*, vol. 15, p. 160.

Kozyrev, N. A. 1956, *Pub. Crimean O.*, vol. 16, p. 215.

Jones, A. Vallance and Hunten, D. M. 1960, *Can. J. Phys.*, vol. 38, p. 458.

Kleman, B. 1956, *Ap. J.*, vol. 123, p. 162.

McKellar, A. 1948, *P. Dom. Ap. O.*, vol. 7, p. 395

McKellar, A. 1960, *A.J.* (paper at A.A.S. April 1960 meeting).

McKellar, A., Welsh, H. L. and Stephenson, F. C. 1955, *A.J.*, vol. 60, p. 170.

McKellar, A. and Richardson, E. H. 1954, *Contr. Dom. Ap. O.*, No. 39.

Marr, G. V. and Nicholls, R. W. 1955, *Can. J. Phys.*, vol. 33, p. 394.

Merrill, P. W. and Wilson, O. C. 1938, *Ap. J.*, vol. 87, p. 9.

Newkirk, G. 1959, *Planetary and Space Science*, vol. 1, p. 32.

Peyron, M. and Broida, H. P. 1959, *J. Chem. Phys.*, vol. 30, p. 139.

Peyron, M., Horl, E. M., Brown, H. W. and Broida, H. P. 1959, *J. Chem. Phys.*, vol. 30, p. 1304.

Phillips, J. G. and Brewer, L. 1955, *Mem. Soc. Roy. des Sci. de Liege*, vol. 15, Fasc. unique, p. 341; Comm. presented at 6th International Colloquium of Astrophysics (Les Particules solides dans les Astres), p. 341.

Richardson, E. H. 1960, *A.J.* (in press). (Paper presented at December 1959 meeting of Am. Astron. Soc. at Cleveland.)

Swings, P. 1941, *Lick O. B.*, vol. 19, p. 131.

Swings, P., McKellar, A. and Rao, K. N. 1953, *R.A.S., M. N.*, vol. 113, p. 571; *Contr. Dom. Ap. O.*, No. 33.

Urey, H. C. and Brewer, A. W. 1957, *Proc. Roy. Soc.*, vol. 241, p. 37.

Wilson, R. 1958, *Ap. J.*, vol. 128, p. 57; *Contr. Dom. Ap. O.*, no. 63.

Wyller, A. 1957, *Ap. J.*, vol. 125, p. 177.

Wyller, A. 1959, *A. J.*, vol. 64, p. 57.

Wyller, A. 1960, *Astrophysica Norvegica* (in press).

ELEMENTS OF ASTROMECHANICS

By Peter van de Kamp
Sproul Observatory, Swarthmore, Pennsylvania

III. The Two-Body Problem; Orbital Velocity, Size and Shape of Orbits

1. *The two-body problem*

Newton's law of gravitation leads to more general knowledge of orbital motions than is contained in Kepler's laws of planetary motion. Recall that for the general case of plane curvilinear motion, expressed in polar co-ordinates referred to the focus,

$$f_r = \frac{d^2r}{dt^2} - r\left(\frac{d\theta}{dt}\right)^2, \tag{1.12}$$

$$f_\theta = \frac{2}{r}\frac{dA}{dt}. \tag{1.14}$$

Elimination of t establishes a relation between r and θ, i.e. the geometry of the orbit. Firstly, since for Newton's law of gravitation

$f_\theta = 0$ and hence $\dfrac{dA}{dt} = 0$, it follows that

$$A = \text{constant} \tag{2.1}$$

i.e. Newton's law of gravitation leads to the law of equal areas (*Kepler's second law*).

Secondly, for the case of constant areal velocity, the time t is now eliminated from the general expression for f_r. Since

$$\frac{dr}{dt} = \frac{dr}{d\theta}\frac{d\theta}{dt} \quad \text{and} \quad \frac{d\theta}{dt} = \frac{2A}{r^2}, \tag{1.3}$$

elimination of $d\theta/dt$ leads to

$$\frac{dr}{dt} = \frac{2A}{r^2}\frac{dr}{d\theta} = -2A\frac{d(1/r)}{d\theta}, \tag{3.1}$$

from which is obtained

$$\frac{d^2r}{dt^2} = -2A\frac{d^2(1/r)}{d\theta^2}\frac{d\theta}{dt} = -\frac{4A^2}{r^2}\frac{d^2(1/r)}{d\theta^2}. \tag{3.2}$$

Also,

$$r\left(\frac{d\theta}{dt}\right)^2 = \frac{4A^2}{r^3}. \tag{3.3}$$

Substitution of (3.2) and (3.3) in (1.12) gives

$$f_r = -\frac{4A^2}{r^2}\frac{d^2(1/r)}{d\theta^2} - \frac{4A^2}{r^3} = -\frac{4A^2}{r^2}\left(\frac{d^2(1/r)}{d\theta^2} + \frac{1}{r}\right). \tag{3.4}$$

For the case of Newton's law of gravitation, the acceleration of a mass m relative to M amounts to

$$f_r = -\frac{\mu}{r^2} \tag{2.8}$$

where
$$\mu = G(M+m). \tag{2.22}$$

Substitution of (2.8) in (3.4) yields

$$\frac{d^2(1/r)}{d\theta^2} + \frac{1}{r} = \frac{\mu}{4A^2}. \tag{3.5}$$

For any one orbit, $\mu/4A^2$ is a constant c; hence the orbit obeys the differential equation

$$\frac{d^2(1/r)}{d\theta^2} + \frac{1}{r} = c. \tag{3.6}$$

Substitution of $y = (1/r) - c$ yields

$$\frac{d^2y}{d\theta^2} + y = 0, \tag{3.7}$$

the differential equation of a simple harmonic motion:

$$y = \alpha\cos(\theta - \theta_0), \tag{3.8}$$

whence
$$r = \frac{1}{c+y} = \frac{1/c}{1 + (\alpha/c)\cos(\theta - \theta_0)}, \tag{3.9}$$

which is the equation in polar co-ordinates with the origin at the focus of a conic section for which

$$p = a(1-e^2) = \frac{1}{c} = \frac{4A^2}{\mu}, \tag{3.10}$$

$$e = \frac{\alpha}{c}, \tag{3.11}$$

$$v = \theta - \theta_0. \tag{3.12}$$

Newton's law of gravitation leads, therefore, to an orbit which is a conic section with the origin at the focus (*Kepler's first law*). The characteristics of the orbit depend on the initial conditions of space, time and

mass; i.e. location, velocity and combined mass of the two bodies. Recall that

$$A = \frac{r\,V\cos\phi}{2}. \tag{1.3}$$

Substitution into (3.10) leads to

$$p = a(1-e^2) = \frac{r^2V^2\cos^2\phi}{\mu}. \tag{3.13}$$

The parameter of the conic section is therefore determined by the initial values of μ, r, and V, and direction ϕ of V. The dependence of a on μ, r and V, as well as the dependence of e on these quantities in addition to ϕ, is discussed in sections 7 and 8 of this chapter.

2. *Kepler's laws. Perturbations*

For the case of an elliptical orbit, therefore, Newton's law of gravitation implies *Kepler's first and second laws*, collectively referred to as *Keplerian motion*.

Kepler's third law is derived by equating the gravitational expression for the inertial constant

$$\mu = G(M+m), \tag{2.22}$$

with the space-time expression for the inertial constant

$$\mu = 4\pi^2\frac{a^3}{P^2}, \tag{2.11}$$

as already referred to in Chapter II, Section 7. The result is

$$\frac{a^3}{P^2} = \frac{G}{4\pi^2}(M+m), \tag{3.14}$$

or, using the astronomical units of space, time and mass, i.e. the astronomical unit of distance, the sidereal year and the mass of the sun (+ earth)

$$\frac{a^3}{P^2} = M+m \tag{2.32}$$

The expressions (3.14) or (2.32) for the *harmonic relation*, are amended forms of Kepler's third law which, as originally stated, is but an approximation for $m = 0$; i.e. negligible planetary mass. Note that the unique relation between semi-axis major and period involves no properties other than the combined mass of the sun-planet binary. The eccentricity of the orbit, for example, does not enter.

Since the ideal of two bodies is but an abstraction, the conic section will always be disturbed, the size of the perturbations depending on the locations and masses of the other object or objects. Though in theory the whole remainder of the physical universe causes perturbations, in practice only those due to comparatively nearby objects need be considered. For example, the amended form of Kepler's third law is correct, except for the mutual perturbations of the planets.

The study of perturbations is beyond the scope of these articles. While there is no general solution for the problem of n bodies, the three-body problem admits of particular solutions.

A perturbation in the motion of a single star or in the orbital motion of a double star indicates a companion object. From the perturbed paths of the primary stars, the companion stars of Sirius and Procyon were thus predicted and their orbits calculated (1844), as well as the fainter component of the faint star Ross 614B (1955); also, the planet Neptune from perturbations in the path of Uranus (1846). Discovered as unseen objects, they were subsequently seen, with larger telescopes which provided sufficient light-gathering and resolving power. We shall return to this subject in Chapter VI.

3. *Gaussian constant*

For the sake of completeness, the Gaussian constant and the corresponding astronomical unit of distance will be mentioned. In studies of sun-planet binaries, the inertial constant is often replaced by

$$k^2 = GM, \tag{3.15}$$

where k is the so-called *Gaussian constant of attraction*, G is the constant of gravitation and M the mass of the sun. Since

$$\mu = G(M+m), \tag{2.22}$$

it follows that

$$k^2 = \frac{\mu}{1 + (m/M)}. \tag{3.16}$$

It is customary to take the sun's mass as unit mass, in which case

$$k^2 = \frac{\mu}{1 + m} \tag{3.17}$$

where m is the planet's mass in terms of the sun's mass. Since the inertial constant may be written as

$$\mu = 4\pi^2 \frac{a^3}{P^2}, \tag{2.11}$$

it follows that

$$k = \frac{2\pi}{P} \sqrt{\frac{a^3}{1 + m}} \tag{3.18}$$

In studies of sun-planet binaries, it is further customary to use the astronomical unit as unit distance, i.e. $a = 1$, and the mean solar day as unit of time. Hence the expression for μ becomes

$$\mu = \frac{4\pi^2}{P^2}, \tag{3.19}$$

and hence

$$k = \frac{2\pi}{P}\sqrt{\frac{1}{1+m}} \tag{3.20}$$

where P is expressed in mean solar days.

For the sun-earth binary, Gauss used the values $P = 365.256385$ mean solar days, and $m = 1/354710$ (combined mass of earth and moon). With these values

$$k = 0.01720209895$$

is found for the Gaussian constant of attraction for sun-planet binaries.

Although improved values of P and m are now available, it has been agreed not to change Gauss' value of k, but to adjust the definition of unit of distance. The period

$$P' = P\sqrt{1+m} \tag{3.21}$$

is introduced; from (3.20), it follows that

$$P' = \frac{2\pi}{k} = 365.2568984 \text{ mean solar days.}$$

The adjusted unit of distance is thus defined as the semi-axis major of an orbit around the sun of an object of negligible mass for which the period of revolution equals P' mean solar days. In this way the Gaussian constant k is invariable.

Since

$$k = \frac{2\pi}{P'} \tag{3.22}$$

the Gaussian constant may be described as the *mean daily motion* for the period P'.

4. *The components of the linear velocity along and perpendicular to the radius vector*

Besides the size a, and shape e of the orbit, the orbital velocity V, is of prime importance.

Formula (1.3) may be written as

$$V = \frac{2A}{r\cos\phi}, \tag{3.23}$$

thus expressing the linear velocity V of, say, m, relative to M in terms of the areal velocity A, the radius vector r and the angle ϕ between the orbital velocity and its component perpendicular to the radius vector. This angle equals the angle of reflection of the radius vector relative to the normal (Chapter I).

In the two-body problem the components of the linear velocity along and perpendicular to the radius vector are given by

$$V_r = \frac{2Ae}{p} \sin v \tag{2.2}$$

and

$$V_\theta = \frac{2A}{r} \tag{2.3}$$

while

$$\tan \phi = \frac{V_r}{V_\theta} . \tag{3.24}$$

Before deriving the general formula for orbital velocity, specific values will be derived.

5. *Circular velocity*

For the velocity V_c in uniform circular motion, $\phi = 0$; hence (3.23) becomes

$$V_c = \frac{2A}{r} , \tag{3.25}$$

which may be written as

$$V_c^2 = \frac{4A^2}{rp} , \tag{3.26}$$

because radius r and parameter p are identical. Or, since

$$p = \frac{4A^2}{\mu} , \tag{3.10}$$

(3.26) becomes

$$V_c^2 = \frac{\mu}{r} , \tag{3.27}$$

the formula for *circular velocity* in any uniform circular motion.

6. *Velocity at perihelion, aphelion, ends of minor axis and latus rectum in elliptical orbit*

Formula (3.23) also yields the linear orbital velocities at perihelion, aphelion and at the ends of the minor axis and latus rectum of an elliptic orbit.

At perihelion $v = 0$, $\phi = 0$, $r_P = a(1-e)$, hence

$$V_P = \frac{2A}{a(1-e)}. \tag{3.28}$$

At aphelion $v = \pi$, $\phi = 0$, $r_A = a(1+e)$, hence

$$V_A = \frac{2A}{a(1+e)}. \tag{3.29}$$

Also,
$$\frac{V_P}{V_A} = \frac{1+e}{1-e}. \tag{3.30}$$

Since
$$\mu = \frac{4A^2}{p} = \frac{4A^2}{a(1-e^2)},$$

or
$$4A^2 = \mu a(1-e^2), \tag{3.31}$$

it follows that
$$V_P^2 = \frac{\mu}{a}\frac{1+e}{1-e} = \frac{\mu}{p}(1+e)^2, \tag{3.32}$$

and
$$V_A^2 = \frac{\mu}{a}\frac{1-e}{1+e} = \frac{\mu}{p}(1-e)^2. \tag{3.33}$$

For $e = 0$, formulae (3.32) or (3.33) reduce to formula (3.27).

At the ends of the minor axis $r = a$, and $\cos\phi = \sin v = b/a$, hence

$$V_b = \frac{2A}{b}. \tag{3.34}$$

Substitution of
$$p = \frac{b^2}{a} \tag{1.30}$$

gives
$$V_b^2 = \frac{4A^2}{b^2} = \frac{4A^2}{pa} = \frac{\mu}{a}. \tag{3.35}$$

Hence, the orbital velocity at the ends of the minor axis is equal to the circular velocity in a circular orbit of radius a (3.27). Or, the "non-perpendicular" circular velocity is always located at either end of the minor axis of an elliptical orbit whose semi-axis major is equal to the radius of the corresponding uniform circular motion.

The velocity V_l at the ends of the latus rectum is easily obtained by substituting $v = 90°$ or $270°$ and $r = p$ in formulae (2.2) and (2.3), i.e.

$$V_{lr} = \pm\frac{2Ae}{p}, \tag{3.36}$$

$$V_{l\theta} = \frac{2A}{p}, \tag{3.37}$$

whence
$$V_l^2 = \frac{4A^2}{p^2}(1 + e^2) = \frac{4A^2}{pa}\frac{1 + e^2}{1 - e^2}, \tag{3.38}$$

or since
$$\frac{4A^2}{p} = \mu, \tag{3.10}$$

the result is
$$V_l^2 = \mu(1 + e^2) = \frac{\mu}{a}\frac{1 + e^2}{1 - e^2}. \tag{3.39}$$

At the ends of the latus rectum, formula (3.24) becomes, after substituting (3.36) and (3.37),

$$\tan \phi = \frac{V_{lr}}{V_{l\theta}} = \pm e. \tag{3.40}$$

The same relation follows, of course, from differentiating formula (1.33) for the ellipse in rectangular co-ordinates:

$$\frac{dY}{dX} = -\frac{X}{Y}\frac{b^2}{a^2} = -\frac{X}{Y}(1 - e^2) \tag{3.41}$$

which for the latus rectum: $X = ae$, $Y = \pm a(1-e^2)$ yields (3.40).

The eccentricity is, therefore, represented in another visual way as the tangent of the angle between the major axis and the tangent at the

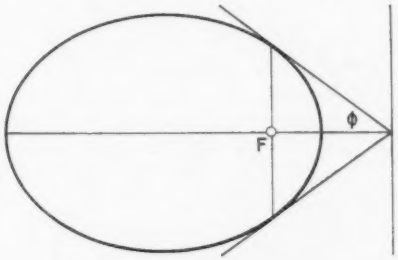


FIG. 3.1—The tangent at the ends of the latus rectum intersects the major axis at the directrix and makes with the major axis an angle of $\phi = \text{arc tan } e$.
For elliptic, parabolic or hyperbolic orbits ϕ is respectively less than, equal to or greater than 45°.

ends of the latus rectum. From the definition of a conic section (1.19) it follows that this tangent intersects the major axis at the directrix. Note that for a circle the directrix is in infinity, which also follows from (1.16).

The derivations in this section hold also for parabolic and hyperbolic orbits, except for the velocities at aphelion and the ends of the minor axis.

7. General formula for velocity in orbit. Circular and parabolic velocity

To recapitulate: in the two body problem, the orbit is a conic section

$$r = \frac{p}{1 + e \cos v}. \tag{1.19}$$

The velocity components V_r and V_θ along and perpendicular to the radius vector are given by

$$V_r = \frac{2Ae}{p} \sin v, \tag{2.2}$$

and

$$V_\theta = \frac{2A}{r} = \frac{2A}{p}(1 + e \cos v), \tag{3.42}$$

while the constant areal velocity A is related to the parameter and the inertial constant by the relation

$$\frac{4A^2}{p} = \mu. \tag{3.10}$$

Hence

$$V_r^2 = \mu \frac{e^2 \sin^2 v}{p}, \tag{3.43}$$

and

$$V_\theta^2 = \mu \frac{(1 + e \cos v)^2}{p}, \tag{3.44}$$

from which the amount V of the linear orbital velocity is found to be

$$V^2 = V_r^2 + V_\theta^2 = \mu \frac{2(1 + e \cos v) - (1 - e^2)}{p}$$

or

$$V^2 = \mu\left(\frac{2}{r} - \frac{1}{a}\right). \tag{3.45}$$

Formula (3.45) contains, of course, the earlier formulae (3.27) for the circular velocity and the velocities at periastron (3.32), apastron (3.33) and ends of the minor axes (3.35), as well as the formula for the velocity at the ends of the latus rectum (3.39).

Since

$$\mu = G(M+m), \tag{2.22}$$

equation (3.45) may be written as

$$V^2 = G(M + m)\left(\frac{2}{r} - \frac{1}{a}\right). \tag{3.46}$$

Formulae (3.45) and (3.46), are basic in all theory and calculation of orbits. They may also be derived from general energy considerations (Chapter V).

For any one orbit with specific values of μ and a, the size of the orbital velocity V depends, therefore, on the length of the radius vector only.

For a parabolic motion, $a = \infty$ and (3.45) becomes

$$V_p^2 = \frac{2\mu}{r}, \tag{3.47}$$

the expression for *parabolic velocity*. Or, since

$$V_c^2 = \frac{\mu}{r}, \tag{3.27}$$

(the expression for the circular velocity derived earlier—which also follows from (3.45) for $r = a$) it will be seen that

$$V_p^2 = 2V_c^2. \tag{3.48}$$

Thus, for any combination of μ and r—i.e. at any location in a gravitational field with inertial constant μ—the *parabolic velocity* ("velocity of escape") amounts to the *circular velocity times the square root of two.*

8. *Construction of orbit. Determination of a and e*

The construction of the orbit from given values of μ, V and r involves the derivation of the length a of the semi-axis major, the length $r' = 2a - r$ of the radius vector to the other "empty" focus and the calculation of the eccentricity e. The orientation of the orbit in its plane, i.e. the major axis, is found by establishing the direction of the other "empty" focus. For this, use is made of the property that the two angles ϕ between the normal and the radii vectores to the two foci, i.e. the two angles of "reflection" (Chapter I), are equal for elliptic, parabolic and hyperbolic orbits alike. Once the other focus has been established, the major axis may be drawn, the centre established and the orbital curve drawn.

For a parabolic orbit the aphelion and the other focus are in infinity and $a = \infty$. For a hyperbolic orbit these quantities, as it were, pass "through infinity". The aphelion branch of a hyperbolic orbit as well as the centre and the other focus appear on the other side, i.e. the concave side of the perihelion branch. Both the semi-axis major (1.22) and the radius vector $r' = 2a - r$ to the other focus, come out negative and are now measured off outside the orbit. The orientation of the orbit is found as for the case of the elliptic orbit.

Formula (3.45) shows that for any combination of μ, V and r, the corresponding value of the semi-axis major a, is dependent only on the size of the linear velocity V and not on its direction. Since

$$\mu = 4\pi^2 \frac{a^3}{P^2} \tag{2.11}$$

the period P also is dependent only on the size of V and independent of direction.

For purposes of calculation the length a of the *semi-axis major* may be found by re-writing (3.45) as

$$a = \mu \frac{r}{2\mu - rV^2}. \tag{3.49}$$

Or, since

$$V_c^2 = \frac{\mu}{r} \tag{3.27}$$

and also

$$V_p^2 = \frac{2\mu}{r}, \tag{3.47}$$

formula (3.49) may also be written as

$$\frac{r}{a} = 2 - \left(\frac{V}{V_c}\right)^2; \tag{3.50}$$

or, as

$$\frac{a}{r} = \frac{1}{2 - (V/V_c)^2}; \tag{3.51}$$

or, also, as

$$\frac{a}{r} = \frac{1}{2} \cdot \frac{1}{1 - (V/V_p)^2}. \tag{3.52}$$

Another useful formula relates μ and a to the velocity V and the parabolic velocity V_p. Substitution of (3.47) in (3.45) yields

$$V^2 = V_p^2 - \frac{\mu}{a}, \tag{3.53}$$

whence

$$a = \frac{\mu}{V_p^2 - V^2}. \tag{3.54}$$

The various expressions for a show that the orbit will be a parabola ($a = \infty$) if the initial velocity equals the parabolic velocity; an ellipse ($0 < a < \infty$), if the initial velocity is lower than the parabolic velocity; and a hyperbola (a negative) if the initial velocity exceeds the parabolic velocity.

If the initial velocity V is perpendicular to the radius vector, the latter obviously lies along the major axis. The "circular" velocity V_c

results in a circular orbit only if the initial velocity is perpendicular to the radius vector.

The *eccentricity* e is derived by eliminating A from

$$4A^2 = \mu a(1-e^2), \tag{3.31}$$

and

$$A = \frac{rV\cos\phi}{2}, \tag{1.3}$$

which yields

$$\mu = \frac{r^2V^2\cos^2\phi}{a(1-e^2)}, \tag{3.55}$$

whence

$$e^2 = 1 - \frac{r^2V^2}{\mu a}\cos^2\phi; \tag{3.56}$$

which since

$$V_e^2 = \frac{\mu}{r}, \tag{3.27}$$

may also be written as

$$e^2 = 1 - \frac{r}{a}\left(\frac{V}{V_e}\right)^2\cos^2\phi. \tag{3.57}$$

For any particular combination of μ, r and V, the eccentricity e varies with ϕ, reaching a minimum value for ϕ = zero—i.e. initial velocity perpendicular to radius vector. In this case

$$e^2 = 1 - \frac{r^2V^2}{\mu a}, \tag{3.58}$$

and also

$$e^2 = 1 - \frac{r}{a}\left(\frac{V}{V_e}\right)^2. \tag{3.59}$$

For any velocity equalling the circular velocity in amount (but not in direction) $r = a$, so that (3.57) reduces to

$$e^2 = 1-\cos^2\phi. \tag{3.60}$$

For $\phi = 90°$, $e = 1$, corresponding to a degenerate parabola in the form of a straight line.

For a parabolic orbit, the other focus is at infinity and the aforementioned construction yields a direction to the other focus—now in infinity—parallel to the major axis. In this case, the true anomaly v is double the angle of reflection ϕ. The perihelion distance $r_P = q = p/2$ (1.42), (1.43) is next obtained from the equation of the parabola in polar co-ordinates

$$r = \frac{p}{1 + \cos v} = \frac{q}{\cos^2(v/2)}. \tag{3.61}$$

Since
$$v = 2\phi, \tag{3.62}$$

it follows that
$$q = r\cos^2\frac{v}{2} = r\cos^2\phi. \tag{3.63}$$

At the ends of the latus rectum $\phi = v/2 = \pm 45°$, a useful property, which also follows from the relation (3.40) derived earlier.

9. *Illustrations*

Figures 3.2 to 3.5 give examples of sets of co-planar, confocal orbits, in each case having the same value of the inertial constant but for velocities differing in amount or direction. The orbits have been constructed in accordance with the precepts given in section 8 of this chapter.

FIG. 3.3—Three co-planar orbits for which the initial linear velocities are equal to the circular velocity, but have differing directions ϕ of 0°, 45° and 60° relative to the perpendicular to the radius vector. Note that for the ellipses, the semi-axis major equals the initial radius vector r, while the initial position is at one end of the minor axis. The distance to the other empty focus is also r; the minor axis lies along the normal to the initial velocity. The eccentricities are calculated from formula (3.60). *Orbit 1*: $\phi = 0°$, $e = 0$; *Orbit 2*: $\phi = 45°$, $e = 0.71$; *Orbit 3*: $\phi = 60°$, $e = 0.87$.

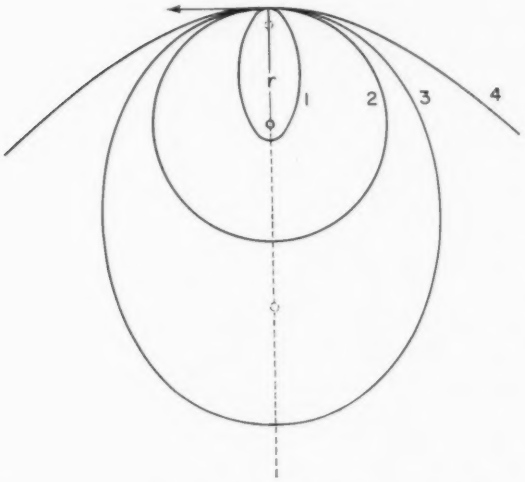
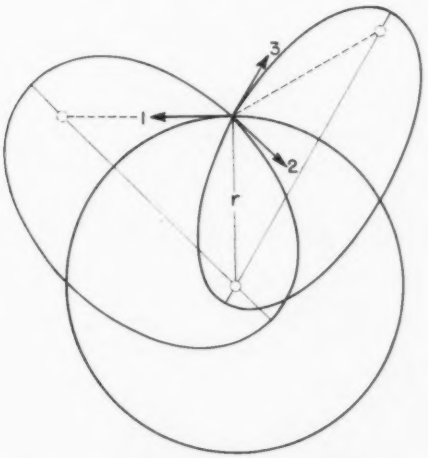


FIG. 3.2—Four co-planar orbits for which the initial linear velocities are perpendicular to the radius vector r ($\phi = 0°$) and are in various ratios to the circular velocity. From formulae (3.51) and (3.59), the corresponding values for a/r and e are found to be: *Orbit 1*: $V/V_c = 0.5$, $a/r = 0.57$, $e = 0.75$; *Orbit 2*: $V/V_c = 1.0$, $a/r = 1.00$, $e = 0.00$; *Orbit 3*: $V/V_c = 1.2$, $a/r = 1.78$, $e = 0.44$; *Orbit 4*: $V/V_c = \sqrt{2}$, $a/r = \infty$, $e = 1$. In all cases the major axis lies along the initial radius vector.



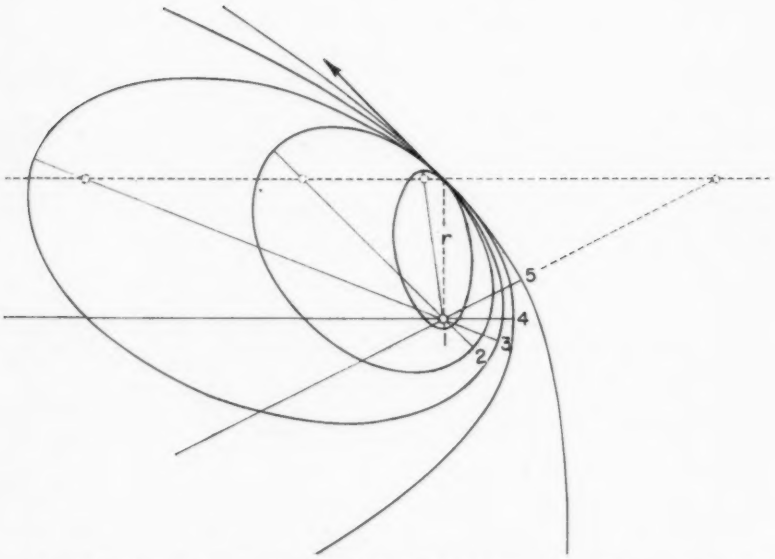


FIG. 3.4—Five co-planar orbits for which the initial linear velocities are at an angle $\phi = 45°$ with the radius vector r, and are in various ratios to the circular velocity. Using formulae (3.51) and (3.57), the corresponding values for a/r and e are found to be: *Orbit 1*: $V/V_c = 0.5$, $a/r = 0.57$, $e = 0.88$; *Orbit 2*: $V/V_c = 1.0$, $a/r = 1.00$, $e = 0.71$; *Orbit 3*: $V/V_c = 1.2$, $a/r = 1.78$, $e = 0.77$; *Orbit 4*: $V/V_c = \sqrt{2}$, $a/r = \infty$, $e = 1.00$; *Orbit 5*: $V/V_c = 2$, $a/r = -0.50$, $e = 2.23$. The perihelion distance for the parabolic orbit is found from (3.63). Since $\cos^2 \phi = 1/2$, $q = r/2$. Note that the different foci lie on a straight line parallel to the axis of the parabolic orbit.

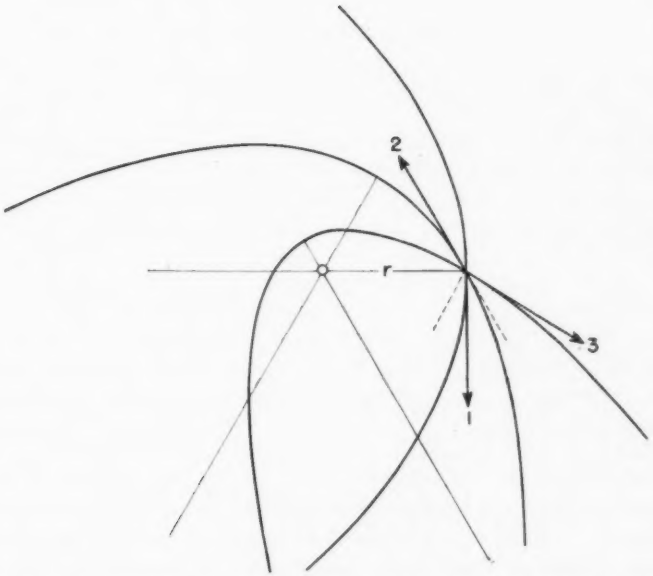


FIG. 3.5—Three co-planar parabolic orbits for which the initial parabolic velocities, at the same location and therefore of the same amount, have differing directions of 0°, 30° and 60° relative to the perpendicular to the radius vector r. The perihelion distances are calculated from formula (3.63): *Orbit 1*: $\phi = 0°$, $q = r$; *Orbit 2*: $\phi = 30°$, $q = 3/4r$; *Orbit 3*: $\phi = 60°$, $q = 1/4r$.

(*To be continued*)

CANADIAN SCIENTISTS REPORT—XXII

ASTRONOMY IN CANADA*

NATIONAL RESEARCH COUNCIL

Spectroscopy Laboratory of the Pure Physics Division—
Report by G. Herzberg

The work of the spectroscopy laboratory of the Pure Physics Division of the National Research Council is devoted to fundamental investigations of the spectra of atoms and molecules from the microwave region to the far ultraviolet. A good deal of the information obtained from these studies is of interest as basic information for the study of the spectra of stars, planets, comets and the interstellar medium. On several occasions specific astrophysical problems have been solved by laboratory investigations at N.R.C., as for example the definite identification of the bands in the spectra of comets around 4050 A. as being due to the free C_3 radical, or the identification of one of the remaining unidentified interstellar lines as being due to CH^+.

A major part of the work of the spectroscopy laboratory is at present devoted to the study of spectra of free polyatomic radicals. Many of these are of potential interest to astronomy. For example, the detailed analysis of the spectrum of NH_2 will be of interest for the understanding of the processes in comets since NH_2 is well-known to occur in comets. More recently a spectrum of CH_2 has been observed in the red part of the spectrum and it appears probable that it may now be possible to identify the presence of CH_2 both in comets and in planets with the aid of this spectrum.

Microwave Section, Radio and Electrical Engineering Division—
Report by A. E. Covington

Various characteristics of the 10-cm. radio emission from the sun, the moon, some of the brighter radio stars, and the galactic plane, are being studied. This work is presently being carried out at Goth Hill Observatory, located about ten miles south of Ottawa on Highway 31. The site, chosen in 1948 as a conveniently located area free from interference, is

*Concluded from p. 87

now rapidly becoming unsatisfactory because of the increasingly large amount of radio interference arising from the expansion of the city. This problem has led to the establishment of a new quiet site for radio astronomy in Algonquin Provincial Park at Lake Traverse. The location was chosen after a careful noise survey in Eastern Canada, and will be developed as a headquarters for this division and interested eastern Canadian universities for experiments which require the absence of radio interference. At the present three buildings are being constructed for occupancy early in 1960.

Since 1947, continuous daily observations of the total flux emitted from the solar disk have been made with a 1.3-m. (4-ft.) parabolic reflector. The results show three simply-isolated emissions which can be readily related to significant optical phenomena. There is an emission from the solar disk which shows prominent limb brightening, an emission from the vicinities of sun-spots, and an intense temporary emission associated with the growing part of the Hα light curve of the solar flare. In addition to their intrinsic solar interest, these results are important to studies of the earth's upper atmosphere. Thus it has been shown that the density of ionization in the E and F layers may be more accurately related to the slowly varying 10-cm. radio emission associated with sun-spots than with other indices such as the area or number of sun-spots. The results of the daily patrol observations may be readily summarized into a daily flux level and any outstanding events. These are currently being distributed to other interested scientists on a daily, weekly and monthly basis. The daily and weekly communications were initiated as an I.G.Y. service in the summer of 1957.

Studies of the properties of individual radio emission regions on the sun are only possible through the construction of large radio telescopes. Although of restricted use, the single-lobed, fan-shaped antenna pattern derived from a long EW aperture has proven useful, and a novel type of interferometer involving an aperture in that direction, 185 metres (600 feet) long, has been developed. The resultant pattern is 1.2′ EW by 2° NS and has been used to produce daily strip scans of the sun during the past year. From a study of the profiles of several radio emission regions, it appears that a lower limit EW extent of these regions is about 1.5′. Future developments of this interferometer will involve increasing the energy-collecting area of the elementary antennas, provision for studies of polarization and use with a NS array for elimination of ambiguities in that direction.

The sensitivity of a radiometer for detecting sources with a continuous spectrum may be increased by increasing the bandwidth of the energy

detected, and has been made possible in the 10-cm. region by the recently developed travelling-wave tube. A radiometer operating from 3000 to 3500 mc./s. has been made and can record temperature changes in a terminal resistance of 0.2°. This has been used with a 3-m. (10-ft.) parabolic reflector and has sufficient sensitivity to allow the detection of the brighter radio stars, the moon, and the galactic plane. The apparatus has been used to obtain an absolute measure of the radio fluxes from the three bright radio stars: Cassiopeia as 134 flux units, Taurus as 71 units, and Cygnus-A as 68 units, where the unit of flux is 10^{-25} watts/-metre^2/cycles/second. Future developments will involve the mounting of this receiver in a larger antenna for a survey of radio stars.

An absolute determination of the radio flux from a source involves a knowledge of the equivalent area of the antenna and a standard of power for calibrating the radio receiver. The first factor has been established through the use of a horn antenna whose gain, and hence equivalent area, may be calculated; while the second factor has involved the construction of resistance terminations which replace the antenna and which may be uniformly heated to an accurately measured temperature. Although such a primary standard has been successfully used, it has proven bulky for everyday use and has led to the calibration of secondary standards such as the fluorescent lamp. Present absolute accuracy in the determination of the solar flux is about ± 7 per cent. and for the brighter three radio stars is of the order of ± 5 per cent.

Upper Atmosphere Research Section, Radio and Electrical Engineering Division—Report by Peter M. Millman

The staff of this section consists of some 30 scientists and technicians. Experimental work is carried out at field stations near Ottawa, at Lake Traverse, Algonquin Park, Ontario, and at various Arctic stations. The scientific programme may be described under five headings.

1. *Meteor research.* Most of this work is now carried out at the Springhill Meteor Observatory. A programme of the radio, photographic, and visual observation of meteors, commenced in 1947, is being actively pursued. The radio work emphasizes the recording of detailed meteor echoes and a continuous counting of radio meteors. IBM machine methods of data reduction are being used to a considerable extent. The photographic meteor programme concentrates on meteor spectroscopy. The visual station accommodates a team of 9 observers in centrally heated cubicles.

2. *Auroral research.* Radio observations of the aurora were made during the I.G.Y. period at 4 sites in Canada. In addition to this a

35-mm. all-sky camera was developed for the auroral photographic programme and used at 9 stations. The recording and collection of visual auroral observations were organized on a large scale. Here again machine methods of data processing have been widely applied. In the post-I.G.Y. period the auroral research is being continued at a reduced tempo.

3. *Radio noise research.* Following studies of radio noise, made during the I.G.Y., equipment is now being designed for special noise studies at Lake Traverse. These will involve a rapid sweep of the noise spectrum (10 to 100 sweeps per second) over the approximate frequency range 20 to 100 mc./s.

4. *Rocket research.* Active participation in Canadian upper atmosphere rocket programmes is planned, commencing in the fall of 1960. The work of this section may include studies of the chemical seeding of the ionosphere, electron density determinations, mass spectroscopy, micrometeorite counting and the firing of artificial meteors.

5. *Ionospheric research.* A number of general studies of the ionosphere are in progress, in particular surveys which involve the interrelation of the aurora, magnetic, ionospheric and solar radiation records of recent years.

Defence Research Board

Report by T. R. Hartz

The activities of the Defence Research Board in the field of astronomy tend to be directed to the applied aspects of astronomy. Some of these studies are often referred to popularly as "space research", but more properly apply to research on the near environment of the earth. In this connection the division between astronomy and certain geophysical studies is usually very arbitrary. This report includes a number of items which apply, in part at least, to the earth's upper atmosphere. However, the astronomical implications are stressed rather than the geophysical.

The research activities summarized here represent work currently in progress at several Defence Research Board establishments. The Defence Research Telecommunications Establishment at Shirley Bay near Ottawa is involved in a majority of the projects since radio techniques are so extensively used. Other establishments concerned are the Defence Research Northern Laboratory at Churchill, Man., the Canadian Armament Research and Development Establishment at Valcartier, Que., and the Prince Albert Radar Laboratory at Prince Albert, Sask.

1. *Solar radio emissions.* Solar radio noise is being monitored continuously at 522 mc./s. using a 20-ft. parabolic antenna and a receiver that is continuously calibrated with a noise diode. Noise emissions from

the disturbed sun are monitored at frequencies near 90, 50, and 30 mc./s. using multiple antennas in the form of interferometers. At 51.7 mc./s. a phase-swept interferometer measures the angle of arrival, in one dimension only, of solar noise enhancements with an accuracy of ± 1 minute of arc. A sweep frequency receiver is now under construction to record noise from the disturbed sun in the frequency range from 20 to 60 mc./s.

These various monitoring projects are being conducted in order to study those abnormal solar phenomena that are the source of the material particles which produce ionospheric disturbances when they reach the vicinity of the earth. The lower frequency radio emissions seem to be very useful in defining some of the properties of the ejected solar particles.

2. *Cosmic noise.* Extra-terrestrial radio emissions at 30 and 60 mc./s. that originate in our own galaxy are being monitored continuously at a number of Canadian stations in order to provide information on radio wave absorption in the upper atmosphere of the earth. At least three distinct types of absorption phenomena have been identified, each of which seems to be intimately related to a particular solar event: (*a*) absorption of relatively short duration at the time of a solar flare, which probably results from the emission of solar X-rays, (*b*) absorption which correlates with auroral and magnetic disturbances, and (*c*) absorption at high latitudes which starts soon after certain large solar flares and persists for several days. The last two types are thought to result from solar corpuscular emissions which differ from each other mainly in the energies of the particles concerned.

3. *Radio star scintillations.* The intense radio source, Cassiopeia A, is being monitored at 53 mc./s. at Churchill and Ottawa in order to study the small-scale structure of the ionosphere and its dependence on the influx of solar particles.

4. *Meteor studies.* The technique of radio wave scattering from the ionization in a meteor trail is being used to determine the intrinsic strength of certain meteor showers. Data on the Quadrantid shower have been obtained for a four-year period.

5. *Rocket programme.* This programme involves the instrumentation of rocket nose cones so that measurements can be made from an elevated platform. Solar radiations, both electromagnetic and corpuscular, are under study, as are their respective effects on the earth's atmosphere. To date instruments have been launched to measure infrared radiation, electron densities in the ionosphere, and cosmic radio noise at a frequency of 3 mc./s. During 1960 measurements will be attempted of radio wave absorption and electron densities as a function of height during a shower of solar particles.

6. *Satellite programme.* A satellite is being constructed and instrumented which will be launched late in 1961 from an American vehicle. The satellite will make radio soundings of the top side of the ionosphere in order to determine electron density profiles.

7. *Very low frequency emissions.* Naturally occurring electro-magnetic radiations in the audio portion of the spectrum are being monitored. Some of these are thought to result from the interaction of impinging solar corpuscles with the earth's magnetic field, while others are thought to originate on the sun.

8. *Spectroscopy and photography.* Spectroscopic and photographic studies of the earth's upper atmosphere are being made, particularly at times of influx of solar particles. Information is obtained on the nature of the particles and on their interaction with atmospheric molecules.

9. *Radio auroral studies.* The abnormal ionization produced by impinging solar particles is being studied through its effect on radio waves. Very-high frequency and ultra-high frequency transmissions are scattered or reflected by the ionization irregularities. As a consequence, it is possible to map the regions of abnormal ionization using the forward-scatter (transmitter and receiver at a large distance from each other) or back-scatter (transmitter and receiver at the same location) techniques. A number of forward-scatter circuits are operating in Canada, and several back-scatter, or radar, equipments are in operation to study the auroral-associated ionization. The large radar installation at Prince Albert is one of these latter equipments: it includes a steerable 84-foot parabolic antenna and a transmitter having a peak power of about 1 megawatt which are used for detailed studies of the radio aurora at a frequency of about 450 mc./s.

10. *Radar astronomy.* Several experimental projects have been undertaken to study radar echoes from the moon at ultra-high frequencies. Interest has been directed to the distinctive fading rates of the signal in terms of lunar or geophysical phenomenon. In particular, efforts have been made to determine electron densities outside the ionosphere and changes in such electron densities following solar disturbances.

Dominion Astrophysical Observatory

Report by R. M. Petrie

Astrophysics. This section describes spectroscopic investigations of normal and peculiar stars, considered as physical and chemical entities. Purposes are to determine the composition of stellar atmospheres and the physical

conditions obtaining therein; this information is useful in studies of stellar structure and evolution and the sources of stellar energy.

1. ζ Aurigae Stars. Much time has been given, by A. McKellar and K. O. Wright, to spectroscopic observations of the so-called ζ Aurigae stars. The systems are composed of a cool supergiant star accompanied by a hot star of normal size. Eclipses of the small star by its giant companion last usually several weeks or months. Observations made near eclipses and at other phases supply detailed information on the atmospheres of supergiant stars at several depths, not obtainable from observation of single stars. Five systems have been studied during the past decade. Principal results are as follows:

(i) atmospheric temperatures vary from about 3,000° K. near the stellar "surface" to about 5,500°K. at heights of 60×10^6 kms.;

(ii) a sharp change in density occurs about 10×10^6 kms. above the stellar surface;

(iii) the outer atmosphere contains local condensation of matter in violent mass motion, the velocities often are 20 km./sec. or more, relative to the stellar surface;

(iv) the radius of the supergiant star is about 200 times that of the sun, the mass is about 20 solar masses, and the luminosity is about 3,000 times that of the sun.

2. Curve of growth analysis. The analysis of late type spectra, in addition to those of the ζ Aurigae stars, has been a continuing programme carried on by K. O. Wright. During the past year a new analysis of the spectrum of Arcturus has been made from improved line intensity measures of FeI lines, and using recent calculations of f values. The range of excitation so covered is 0 to 4.4 volts. The deduced curve of growth appears to conform to that from a single temperature atmosphere at 3,400°K.

3. High-temperature stars. Spectra of the very hot O and W stars are being analysed in detail by A. B. Underhill. The spectra show broad emission features in addition to absorption lines. Main conclusions are: (i) the level of ionization ranges from about 10 volts to about 100 volts; (ii) large mass motions are characteristic of the atmospheres; (iii) the atmospheres tend to be unstable forming "halos" or "shells", and it is likely that matter is ejected from the stars. The work is being continued and it is hoped to clarify the relationships between the various (spectroscopic) types of hot stars.

An intensive theoretical programme is being carried out to advance the interpretation of early-type spectra. Computations of "model atmospheres" are being made with an electronic computer, to cover a sub-

stantial range in surface temperature and surface gravity. The results will appear in the form of predictions of the emergent spectrum of the star. The data may be used to study the ultraviolet spectra, to estimate the abundance of helium, and generally to advance our knowledge of the outer layers of the hottest stars.

4. Molecules in stellar spectra. Studies of spectra of relatively cool stars exhibiting bands characteristic of absorption by certain molecules are being pursued by A. McKellar. The Swan bands in spectra of 22 R stars and 25 N stars have been analysed to obtain the abundance ratio of the carbon isotopes C^{12} to C^{13}. A recent improved value obtained by J. L. Climenhaga is $C^{12}/C^{13} = 5$, in good agreement with the value predicted from nuclear reactions assuming the carbon-nitrogen cycle to be supplying the stellar energy. Of 47 stars so far studied all but four show this low value to the isotope abundance ratio. The ratio for the remaining four stars is estimated at about 100, agreeing with terrestrial and meteoritic values.

The intensity of the NH band at $\lambda 3360$ is being measured in spectra of G and K giants typical of the two stellar populations. The CN bands are found to be stronger for population I, than for the population II, representatives. The measurements so far show a surprisingly small range in the intensities of the NH bands.

5. Variable stars. Several of the high-temperature, short-period variables of the β Cephei type are being followed in detail by G. J. Odgers. High-dispersion spectrograms have been obtained covering cycles of β Cephei, 12 Lacertae, and BW Vulpeculae, while lower dispersion coverage has been obtained for some of the fainter stars. Radial-velocity curves have been determined as well as the variation of emission intensity at $H\alpha$ and the variation of the shapes of absorption lines.

A possible explanation of the behaviour of β Cephei variation has been given in terms of a shock-wave originating below the stellar photosphere and being dissipated as it passes outward through the atmosphere. The shock-wave may be produced by the instability of the helium and hydrogen convective zones in certain critical stellar dimensions. The explanation has achieved some success in explaining the observed atmospheric motions in β Cephei, classical Cepheid, and long period variation and may be of value in studying stellar variability, generally.

6. Solar-system spectroscopy. Cometary spectra are obtained whenever the opportunity presents itself. Analysis of these spectra gives information about the physical state of comets and the method of excitation of their radiations.

Spectra of Venus and the moon are being obtained by E. H. Richardson

in an attempt to confirm the existence of the bands in the Venusian spectrum, announced by Kosyrev. Spectra to date fail to reveal the bands and the observations now will be directed toward obtaining spectra of the short-lived dark areas of the planet, or of its atmosphere.

Stellar Motions and Distribution. Radial velocities, spectral types, and absolute magnitudes, especially of distant stars, star clusters, and loose aggregations are required for studies of galactic structure and dynamics, of the interstellar material, and of the formation and evolution of stars.

1. B-type stars. Radial velocities of 550 distant B stars have been determined by R. M. Petrie and J. A. Pearce. The apparent magnitudes range between 7.5 and 9, the spectrograms are of moderate single-prism dispersion. Nearly one-half of the stars exhibit variable velocity caused, presumably, by binary orbital motion. The velocity of the interstellar calcium has also been measured. Spectrophotometric measures of the absorption at Hγ are proceeding for the determination of the absolute magnitudes and distances of the individual stars.

Line intensities in spectra of about 100 B stars have been determined by J. K. McDonald. The measures of line strengths will be used to construct a system of spectral classification and to study the distribution of spectral types among the B stars.

2. Star clusters and aggregates. Radial velocities, spectral types, and absolute magnitudes, have been obtained of stars in and near the Praesepe cluster by J. K. McDonald. Twelve new cluster members have been found situated between 1° and 2.5° of the centre of the cluster.

Radial velocities and spectral types of faint stars in five galactic clusters are being obtained by A. B. Underhill. These data will determine cluster membership of individual stars and give information on the absolute magnitudes of O stars.

Spectroscopic observations of the so-called expanding O-associations, ζ Persei, Lacerta, and h,χ Persei, are being made by G. J. Odgers, J. K. McDonald, and R. M. Petrie, respectively. The purpose is to decide, if possible, upon the reality of the expansion as deduced from proper motion studies.

3. Galactic Pole programme. Spectra of 180 stars, of spectral types A to F5, apparent magnitudes 6 to 9.0, and situated within 10° of the north galactic pole have been obtained by R. M. Petrie and G. J. Odgers. Radial velocities, spectral types, and absolute magnitudes are being determined. The data will give an estimate of the density of the galaxy in the neighbourhood of the sun.

Binary Stars. Binary stars are studied to obtain knowledge of the masses, luminosities, and dimensions of stars and to investigate the orbital motions especially in the massive, high-temperature, systems. Spectroscopic observations of binary stars are essential to progress in several branches of astrophysics.

1. Orbital variations. A programme of re-observation of known spectroscopic binaries has been carried out by E. G. Ebbighausen and R. M. Petrie. Second and third "orbits" have been determined for six systems in one of which, H.R. 8800, marked apsidal motion was discovered. The programme is a continuing one, twelve binaries being currently under observation.

2. Visual binaries. Spectroscopic observations of eight visual binary systems are being made on a long-term programme, by A. B. Underhill. Radial-velocity curves will give masses and absolute dimensions. Short-period variations in radial velocity have been detected in some of the systems.

3. Orbital elements. The orbits of two high-temperature two-spectrum binaries, not hitherto known, are being determined by R. M. Petrie.

Instrumental Development. The provision of more powerful observational facilities and the development of new types of analysing equipment are an essential part of the Observatory's research programmes. Planning the expansion of equipment is under the general supervision of A. McKellar. Details of design and fabrication are carried out by D. H. Andrews and the shop staff, A. R. Salonen and J. R. White.

1. Present construction. A new fast spectrograph has been built for use with the 72-inch telescope. This is an all-reflection, grating, spectrograph employing an inverted Cassegrainian collimator and a Schmidt camera. Dispersions available at first are: 40 A./mm. in the violet region, and 60 A./mm. in the red region.

Construction is proceeding on a new microphotometer to analyse stellar spectrograms. The instrument will supply a strip-chart record of a spectrogram, intensities being recorded on a linear scale.

2. Design. Design is proceeding on a powerful Coudé spectrograph for future use with the 48-inch telescope, the delivery of which is expected in 1961. The spectrograph will be an all-reflection instrument of the general type installed at the Hale telescope on Palomar Mountain. Two gratings and two cameras are to be provided giving high resolving power and linear dispersions ranging from 3.4 A./mm. to 10.3 A./mm. in the violet, and ranging from 5 A./mm. to 15.5 A./mm. in the red.

Future plans include the automation of radial-velocity measurements. A scanning unit and an oscilloscope display unit have been designed and some of the parts have been acquired. The project, as presently contemplated, will eventually make the process fully automatic.

University of Western Ontario

Report by William Wehlau

Astronomy and Related Topics. The research programmes in progress can be divided into the direct investigation of astronomical problems employing observational data, and laboratory studies to provide data and information on physical processes of significance in astronomical applications. The teaching programme and student investigations are, of course, closely related to these programmes. The introduction in 1959 of an Honours Degree in Astronomy as one of the options in the Department of Mathematics and Astronomy and the appropriate Honours Courses are providing additional opportunities for students interested in astronomy.

The programmes dealing directly with astronomical observations currently in progress are:

1. Photoelectric photometry of peculiar A stars. Photoelectric observations are being made of a number of peculiar A stars to determine which are variable and to study the nature of the light variability. The observing list includes about 20 stars, selected for the most part from those with strong Si II lines in their spectra. Several hundred observations have been obtained and are being analyzed. Since the amplitudes expected are a few hundredths of a magnitude, the random and systematic errors must be kept small and will invalidate many observations. A typical value for the probable error of the difference in magnitude of two constant comparison stars in the blue is 0.004 with a single observation of each star.

2. Spectrophotometry of peculiar A stars. High dispersion spectra, 4.5 A./mm., of several peculiar A stars obtained at the Dominion Astrophysical Observatory are being used to study the atmosphere of these objects. Three of the stars, 73 Dra, ϵ UMa and χ Ser, are spectrum variables and the variations in their spectra are being studied. The spectra will also be compared with that of γ Gem, a normal sharp line A star. γ Equ and β CrB, late A or early F spectral types, are being compared with the normal F stars ν Her and σ Boo.

3. A determination of the orbit of the spectrographic binary H.D.

174369, using plates on loan from the David Dunlap Observatory, is in progress.

The above programmes are being carried out in the Hume Cronyn Memorial Observatory.

4. Magnetic properties of meteorites. An investigation of the magnetic properties and remnant magnetic fields of meteorites, particularly the Dresden Meteorite, is being carried out in the Geophysics Department.

The laboratory programmes are as follows: Research Programme of the Molecular Excitation Group, Department of Physics. The aims of this research programme are:

1. To provide basic atomic and molecular data in terms of transition probabilities (and related parameters), excitation functions etc. for transitions of astrophysical, aeronomical, combustion and radiation chemical interest.

2. To study mechanisms and processes of excitation of the above spectra in the laboratory.

Experimental Studies

1. Intensity measurements upon molecular band systems of importance in the above fields of interest. Measurements have been made upon about 20 important band systems of such molecules as O_2, N_2, O_2^+, CN, C_2, C_3, CO, CO^+, N_2^+, over the past few years.

2. Identifications of molecular spectra. A continuing programme has been recently started to photograph completely, on a variety of dispersions, band systems of interest and to produce in compact report form (one for each band system) as much of the data on that system as is essential for its accurate identification. Identified photographic charts, Deslandres tables, wave-length tables and essential bibliographies will be included in each report. Such reports are intended to supplement *The Identifications of Molecular Spectra* by Pearse and Gaydon. Band systems of N_2, N_2^+, and CN are currently being photographed.

3. (i) Excitation of spectra. The shock tube is an excellent laboratory tool with which to excite spectra thermally which are difficult to excite (without interfering lines) by more conventional means. Thirty oxides (Al_2O_3, V_2O_5 etc.) were shock excited over a range of Mach numbers (3–9) by helium driven shock waves in argon. A number of spectra of powdered meteorite specimens were also shock excited in pilot studies. They seem to duplicate much of what is photographed in meteors in flight.

(ii) Spectroscopic study of the hot gas. Time-resolved spectroscopic studies in emission and absorption have been used to study the growth

and decay of emitting species in the hot gas of the powder particle-shock wave interaction. Spectroscopic temperature measurements have been made of the hot gas by means of "doping" the gas with the thermometric molecule CN and measuring its rotational temperature. A shock tube is being set up to study shock-initiated detonation waves.

(iii) Ablation of the solid. Photomicroscopic statistical particle size measurements before and after shock treatment have provided information on the ablation mechanisms.

4. Excitation of spectra in gases by energetic ion beams. The motivation of this work was through the interest in excitation of atmospheric gases by solar protons giving rise in part to the auroral luminosity. Three sets of experiments have been undertaken using 2–4 Kev. lithium ions, $\frac{1}{2}$–$1\frac{1}{2}$ Mev. protons (at A.E.C.L., Chalk River) and 3–5 Mev. alpha particles. In each case spectral identifications of the feeble luminosity, measurements upon the variation of spectral features with ion current and pressure and spectroscopic temperature measurements have confirmed that charge transfer with excitation (and sometimes dissociation) is the dominant mechanism for a diatomic target. Large aperture spectrographs were built for this work and a 100 Kev. proton accelerator has recently been constructed to extend the research programme.

5. Measurements of lifetimes of the intermediate state of two optical transitions in cascade. Preliminary experiments have been performed to attempt to measure the lifetime of the $B^3\Pi$ state of N_2 by using delayed coincidence techniques in the recording of photons from the two transitions ($C^3\Pi \rightarrow B^3\Pi$), ($B^3\Pi \rightarrow A^3\Sigma$) in cascade.

6. Gaseous electronics. Spectroscopic studies are being made upon point-to-plane corona discharges in gases, the plasmas produced by exploded wires, and plasma jets.

Theoretical Studies

1. Calculation of Franck–Condon factors and *r*-centroids of molecular band systems. A continuing programme of calculations of arrays of Franck–Condon factors has been programmed for digital computers and information is available for nearly 40 important band systems. The *r*-centroid concept has been explored, physical meanings attached to the *r*-centroid, methods evolved for calculation of *r*-centroid arrays for band systems, and arrays computed for about thirty systems in a routine fashion.

2. Study of diatomic molecular potentials. The Klein–Rydberg and Dunham methods of evaluating molecular potentials from measured wave-lengths have recently been shown to be almost identical, and

methods have been derived for evaluating such potentials very simply. The method has been programmed for a computer and data are available for nearly thirty potentials.

3. Study of excitation cross-sections. Quantal calculations of cross-sections for excitation by slow electrons of certain levels of H are in progress.

The programme of the Molecular Excitation Group is carried out in the Physics Department by three staff members, two research associates, and six post-graduate students.

Coincidence phenomena in coherent light beams. This is an experimental study of the physical basis of the Brown and Twiss intensity interferometer. The problem can be briefly stated as the determination of the number of coincident arrivals of photons at two photomultipliers. If the photomultipliers are illuminated with coherent light, theory predicts that more coincidences will be observed than would be expected from purely random coincidences. The variation of this effect with polarization, resolving time and line width has been investigated as a co-operative programme of the Hume Cronyn Memorial Observatory and the Physics Department. Further work is in progress to obtain more reliable data on the effect.

ROYAL ASTRONOMICAL SOCIETY OF CANADA

Two meetings of the National Society were held in the Spring of 1960, the Annual Meeting in Toronto on March 11, and a two-day meeting combining the General Assembly and Session for Papers in Montreal on April 8 and 9. The reason for separating the two meetings is that, according to the terms of the incorporation of the Society, an annual business meeting must be held in the province of incorporation, namely Ontario.

MINUTES OF ANNUAL MEETING AT TORONTO, MARCH 11, 1960

The Annual National Meeting was held at 8:00 p.m. on Friday, March 11, 1960, in the Wallberg Chemical Engineering Building of the University of Toronto, prior to the regular meeting of the Toronto Centre. Miss Ruth J. Northcott, Second Vice-President, presided.

Miss Northcott expressed the regrets of the President, Dr. Andrew McKellar, and the First Vice-President, Dr. Peter M. Millman, who were unable to attend. She pointed out that this year there will be, in effect, two national meetings, an "official" annual meeting in Toronto because of the incorporation of the Society under an Ontario charter, and the "two-day" meeting in Montreal for the presentation of the President's address and a session of papers by members.

Minutes of the Annual Meeting held in Toronto on March 13, 1959, were adopted as printed in the JOURNAL (June 1959).

In the absence of Mr. J. E. Kennedy, National Secretary, on account of illness, Dr. L. Searle presented the Secretary's report and read a list of the deceased members while those present stood in silent tribute.

Mr. J. H. Horning, National Treasurer, presented a summary of the annual financial statement, and also the report of the Board of Trustees on the headquarters property and the Society's special funds. He noted that his duties had been made much easier this past year by the efficient operation of the office by Mrs. M. Fidler, the Executive Secretary, and the voluntary aid given by the Auditor, Mr. M. A. Altman. The meeting directed that a letter of thanks be sent to Mr. Altman.

Dr. W. T. Tutte, Librarian, reported on the operations of the Library and the sale of back issues of the Society's publications.

Miss Northcott then read a brief report of the President on behalf of Dr. McKellar. In this, Dr. McKellar commented not only on the Society's progress but also on several advances made in the science of astronomy in the past year.

All the reports having been printed as a supplement to the JOURNAL and distributed to members, were duly received and adopted by the meeting.

Before turning the chair over to Dr. Searle to continue with the regular meeting of the Toronto Centre, Miss Northcott outlined for members present some of the programme and features planned at the Montreal meeting on April 8th and 9th.

FREDERIC L. TROYER, *Recorder.*

REPORT ON MEETING AT MONTREAL, APRIL 8 AND 9, 1960

At the invitation of the Montreal Centre, the two-day meeting was held in Montreal, P.Q. Following a dinner tendered the National Council by the Montreal Centre at the Laurentien Hotel, the General Assembly was held in the McConnell Engineering Building, McGill University, with the President, Dr. Andrew McKellar, in the chair. Eight of the fourteen centres were represented: Quebec, Montreal, Montréal, Ottawa, Toronto, Hamilton, Edmonton, and Victoria. A number of members not attached to centres were also present.

The scrutineers' report on balloting was presented: a majority of the 625 ballots returned resulted in election of the list of officers shown on p. 143.

During 1959 Honorary Membership in the Society was accepted by two distinguished astronomers from abroad (see p. 142). The Society learned with sorrow of the death on February 22, 1960 of a distinguished Honorary Member, Dr. Samuel A. Mitchell, famous for his solar eclipse work. The number of Honorary Members is now fourteen.

The Chant Medal was awarded for 1959 to Earl R. V. Milton of Edmonton, who is a candidate for the doctor's degree in Chemistry at the University of Alberta. Mr. Milton joined the Society in Montreal while a high-school student and participated actively in observing programmes. Upon moving west in 1952 he organized the Edmonton Centre groups for the observations of meteors and aurorae and has recently been appointed chairman to co-ordinate the Society's observing on a national scale.

The National President gave Service Awards to four members (see p. 142).

The Vice-President, Dr. Peter M. Millman, took the chair for the address by the President (p. 97); refreshments were provided by the two centres in Montreal.

Members presented the following papers on Saturday morning, April 9:

The Photoelectric Programme of the A.A.V.S.O., *John J. Ruiz*, Dannemora, N.Y.
Some Observations of Changing Reflectivity in a Local Area of Lunar Surface, *Raymond R. Thompson*, Toronto Centre.
The Edmonton Survey of the Aurora Borealis, *Earl R. Milton*, Edmonton Centre.
Stellafane Meeting, 1959, *Gordon A. Grant*, Ottawa Centre.
Influence of the Weather on Seeing Conditions, *S. A. Zielinski*, Fulford, P.Q.
Celestial and Inertial Navigation in Space Travel, *Carlos Fallon*, Springfield, Pa.
From Observing to Observatory, *F. Lunn*, Montreal Centre.
The New Station of the U.S. National Observatory, *Helen S. Hogg*, Toronto Centre.
The Dominion Radio Astrophysical Observatory, *John L. Locke*, Penticton, B.C.
Central Meridian Transits, *Geoffrey Gaherty, Jr.*, Montreal Centre.
The Telescope Makers Group, Toronto Centre, *Jesse Ketchum*, Toronto Centre.
A Solar Eclipse Expedition, *W. A. Gault*, Ottawa Centre.
Mars: A New Concept About Seasons, *Jean Asselin*, Centre Français de Montréal.
Observations of Variable Stars, *Francis T. Morgan*, Montreal Centre.
Observing Satellites with Simple Instruments, *G. A. Bakos*, Cambridge, Mass.
Luminosity Functions of Galactic Clusters, *D. Sher*, Toronto Centre.

A new and impressive feature at this meeting was a display of various aspects and results of observing done by the centres, including pieces of the recently-fallen Bruderheim meteorite. Over ninety display placards, 22×28 in., were contributed as follows: Calgary (8), Edmonton (30:), London (2), Montreal (26), Montréal (4), Ottawa (8), Toronto (10), and Winnipeg (3+).

At the Society's Luncheon at the Berkeley Hotel Earl Milton gave interesting details on the spectacular Bruderheim meteorite which fell near Edmonton, March 4, 1960.

Afternoon activities were divided among a Council Meeting, observation group discussion and tours of the city, ending with tea by invitation of le Centre Français de Montréal at St. Helen's Island. Many members took advantage of the open house of the Observatory of the Montreal Centre to see and admire the excellent equipment.

NEW HONORARY MEMBERS

Dr. V. A. Ambartsumian

Dr. Bart J. Bok

DR. V. A. AMBARTSUMIAN, Director of the Burakan Observatory in Soviet Armenia. Dr. Ambartsumian, a former Vice-President of the International Astronomical Union and a former Professor of Astronomy in Leningrad University, has directed the Burakan Observatory since its founding in 1943. An acknowledged authority in stellar astronomy and astrophysics he is presently engaged in research for the Soviet Academy of Sciences on the problem of the galaxies.

DR. BART J. BOK, Director of Mount Stromlo Observatory at Canberra, Australia. Dr. Bok, born and educated in the Netherlands, was associated with Harvard University and the Harvard College Observatory from 1929 until 1957 when he accepted the appointment of Professor of Astronomy at the Australian National Observatory and Director of Mount Stromlo Observatory. He is an outstanding authority in the field of galactic structure, especially in that part seen from the southern hemisphere.

NEW SERVICE AWARDS

J. H. HORNING, nominated by the National Council. Mr. Horning, a member of the Society since 1914, Recorder in 1923, Councillor from 1924 to 1931, has been National Treasurer since 1932 until the present when he is retiring from that office. He remains one of the Society's Trustees. As Treasurer over the years, he has watched the Society's financial affairs grow from a few simple accounts to something approaching "big business". During the lean years he urged caution but remained optimistic, and succeeded in obtaining increased Government support when the financial situation appeared desperate. During the good years he was the first to support bold and wise expenditures for the good of the Society. Few officers have given so much of their time and counsel.

CHARLES M. GOOD, nominated by the Montreal Centre. Mr. Good has served the Montreal Centre continuously since 1943 in such varied offices as Councillor, Librarian, Vice-President, President and Representative to National Council. He was in a large measure responsible for the establishment of the Centre's Observatory, and has participated in observations, particularly occultations, of which he is Chairman. For many years he has ably directed the very effective public relations of the Montreal Centre.

FLEURANGE LAFOREST, nominated by le Centre Français de Montréal. Miss Laforest was one of the founders of the Centre in 1947 and, since 1950, has occupied the office of Secretary-Treasurer and is the Centre's Representative to National Council for 1960. During these years she has worked tirelessly for the Centre, recruiting members, organizing programmes, expeditions and observing meetings. The members acknowledge her as the spirit and binding force which has kept the Centre alive and flourishing in good years and bad.

FREDERIC L. TROYER, nominated by the Toronto Centre. Mr. Troyer joined the Society in 1924 while still a schoolboy. Appointed in 1925 as Assistant Curator, he has held office continuously ever since in one or the other of the Toronto Centre and the National Society. At present Secretary of the Centre, he has been also Recorder, Vice-President and President. For many years he has been the organizer and the mainstay of the Centre's summer activities in city parks and at the Canadian National Exhibition and through his untiring efforts has introduced hundreds of persons to the study of astronomy.

NATIONAL OFFICERS AND COUNCIL FOR 1960

Honorary President—The Hon. W. J. DUNLOP, D.PAED., Minister without portfolio.

President—ANDREW MCKELLAR, PH.D., F.R.S.C.,* Victoria
First Vice-President—Peter M. MILLMAN, PH.D., F.R.S.C., Ottawa
Second Vice-President—RUTH J. NORTHCOTT, M.A., Toronto
National Secretary—J. E. KENNEDY, M.SC., 252 College Street, Toronto 2B
National Treasurer—WILLIAM R. HOSSACK, PH.D., 252 College Street, Toronto 2B
Recorder—FREDERIC L. TROYER, Toronto
Librarian—W. T. TUTTE, PH.D., F.R.S.C., Toronto
Council—

Elective Members: ANNE B. UNDERHILL, PH.D., Victoria; DAVID A. KEYS, PH.D., F.R.S.C., Deep River; FRANK J. DEKINDER, Montreal

Past Presidents: HELEN S. HOGG, PH.D., F.R.S.C., Toronto; R. M. PETRIE, PH.D., F.R.S.C., Victoria

Representatives from Centres:

Calgary Centre: E. J. MCCULLOUGH, T. W. LAVIOLETTE (President)
Edmonton Centre: EARL MILTON, B.A., J. HARRINGTON (President)
Halifax Centre: REV. M. W. BURKE-GAFFNEY, S.J., B. W. ALLEN (President)
Hamilton Centre: G. M. VANSICKLE, S. J. BUNTAIN (President)
London Centre: W. GORDON GRAHAM, R. W. RICHARDSON (President)
Montreal Centre: C. M. GOOD, A. R. MACLENNAN (President)
Centre Français de Montréal: FLEURANGE LAFOREST, PIERRE LEMIEUX (President)
Ottawa Centre: W. L. ORR, M.D., IAN HALLIDAY, PH.D. (President)
Quebec Centre: MAURICE DROLET, J. ALFRED DUMONT (President)
Toronto Centre: JOHN F. HEARD, PH.D., F.R.S.C., LEONARD SEARLE, PH.D. (President)
Vancouver Centre: J. A. JACOBS, PH.D., F.R.S.C., V. J. OKULITCH, PH.D., F.R.S.C. (President)
Victoria Centre: NORMAN G. ROGERS, J. A. L. MUIR (President)
Windsor Centre: WILLIAM G. MITCHELL, LAMBERT HUNEAULT (President)
Winnipeg Centre: R. J. LOCKHART, B.A., J. SCATLIFF, M.D. (President)

(The officers of the Centres are printed in the *Supplement*, p. 18)

*Deceased, May 6, 1960–EDITORS

REVIEW OF PUBLICATIONS

Extensive Air Showers by William Galbraith. Pages 211; $5\frac{1}{4} \times 8\frac{1}{2}$ in. Butterworth & Co. (Canada) Ltd., Toronto. Price $7.50.

The study of cosmic ray extensive air showers is of interest in nuclear physics, astrophysics and cosmology, as well as requiring some knowledge of the earth's atmospheric structure. These showers of secondary particles and radiation in the atmosphere are believed to start from one primary cosmic particle of extremely high energy, higher than any other known particle energy by many orders of magnitude.

Galbraith's work covers the field in a competent and comprehensive manner. The explanations are in sufficient detail that the book could be used by a student of physics with little or no specialized knowledge of the subject yet the theoretical treatment is as complete as could be expected in a work of this type. Perhaps one of the greatest difficulties in writing on this subject is that the theory of the passage of energetic particles through matter is so very involved that the best an author can do is outline the physical principles and quote formulae from more highly specialized works. A complete derivation of all the formulae used would take volumes. The selection in this case is good and it is written in an understandable way.

The chapter sub-division is well arranged. Placing references at the end of the book is perhaps better than placing them at the end of each chapter though less convenient to the reader than having them in the context or at the bottom of the page. The references, however, are comprehensive and should be useful to students making a more detailed study. The author made a careful study of the literature and the number of references to Russian literature is such that he cannot be accused of neglect in that respect.

A more careful explanation of symbols used would have eased the reading or, better still, a table of symbols preferably for each chapter. In a number of cases the reader had to turn back several pages to find the meaning of a particular symbol. The publishers are to be congratulated on keeping the price of this book at a reasonable level.

D. C. Rose

Astronomy by Theodore G. Mehlin. Pages 392; $6 \times 9\frac{1}{4}$ in. New York, John Wiley & Sons, Inc., 1959. Price $7.95.

This text-book by the Field Memorial Professor of Astronomy at Williams College, U.S.A., has several attractive features. Most text-books devote the first half or more of their pages to the solar system. Mehlin's approach is stimulating: telescopes, atomic structure and spectrum analysis in 30 pages; stars, the expanding and steady state theories, sources of stellar energy, mass-luminosity relation, spectrum classification, Hertzsprung–Russell diagram, stellar evolution, Types I and II and white dwarfs—all this in the next 30 pages; then stellar distances, magnitudes and motions; 26 pages on the sun and about the same on binary stars; an excellent chapter on intrinsic variables and by the middle of the book we have surveyed galaxies and the red shift. After this come some details of our galaxy, nebulae, planetaries, clusters. The last 140 pages deal with the solar system, rockets and artificial satellites and give a good survey of some theories of the origin of the solar system. Co-ordinate systems, time and the calendar are briefly discussed in appendices.

Not enough is given about the results of radio astronomy. One wonders why absolute temperature is referred to on p. 36, with one equivalent in degrees Fahrenheit and another in degrees Centigrade and thereafter always as degrees Kelvin. In dealing with stellar spectra, why do authors of text-books omit a Class O spectrum while reproducing typical A to M spectra? The discussion of the possible internal structure of the major planets is hardly up-to-date. The second to last sentence on p. 39 is misleading, as is also the statement (p. 42) "four hydrogen nuclei are added progressively to the original carbon atom . . .". Comet Arend-Roland (1957) is illustrated with "a spike tail toward the sun" but the plausible explanation of this phenomenon is not mentioned.

Most of the illustrations and diagrams are excellent. Although one looks in vain for the names of some of the great contributors to astronomy, and in spite of an inadequate index (no reference to Copernicus, Jansky, precession . . .). This book should have a place on our shelves.

A. Vibert Douglas

Contemporary Physics: A journal of interpretation and review, vol. 1, no. 1, October 1959. Pages 80; $7 \times 10\frac{1}{4}$ in. London, Taylor and Francis Ltd. Price 75 cents; annual subscription (6 parts) $4.00.

This first number of an important new review journal of physics will be of great interest to a wide variety of readers of the Journal. The

aim of *Contemporary Physics* is to publish review articles on various aspects of physics, maintaining the highest level of scientific content, and at the same time to interpret this content in a way that the ordinary university graduate can understand.

Teachers in the schools, physicists in industry and scientists in fields related to physics will all benefit from this enterprise. Astronomers striving to keep in touch with the rapid development of modern physics will appreciate the efforts of the distinguished contributors to provide lucid introductions to a diverse selection of areas of active progress in physics. They will appreciate too the detailed reviews of new books in physics.

In the first number of *Contemporary Physics* Prof. C. N. Hinshelwood, President of the Royal Society, writes: "Some of the most exciting adventures of modern times occur in the field of physics. . . . It is very difficult for any but experts to understand what is going on, not, as so many non-scientific people are fond of asserting, because men of science are incapable of expressing themselves clearly or are unwilling to try, but for the simple reason that many aspects of the subject are of very great inherent difficulty. . . . It is clear, therefore, that a very valuable purpose can be served by a journal in which experts will endeavour to present the whole field in perspective to a wider circle of their scientific colleagues."

This first number contains, among others, articles by Prof. O. R. Frisch (Molecular beams), Dr. R. J. Blin-Stoyle (The structure of the atomic nucleus) and Dr. L. Kellner (Alexander von Humboldt and the organization of international collaboration in geophysical research). These and the other contributions are lucidly written and they contain valuable bibliographies.

Contemporary Physics has got off to an excellent start; if it maintains the high standard set by its first number it will perform an important service for the scientific community.

LEONARD SEARLE

Russian-English Glossary of Optics and Spectroscopy edited by I. Emin. Pages 78; $8\frac{1}{4} \times 10\frac{1}{2}$ in. (paper). New York, Interlanguage Dictionaries Publishing Corp., 1959. Price $10.00.

This dictionary contains an up-to-date Russian-English vocabulary in the fields of optics and spectrocospy. Over 4000 terms compiled from the latest literature are included. It will prove valuable for all who wish to read the Soviet literature in these fields. While the existence of dictionaries of this type will help remove the barriers between western scientists and the Soviet literature, the price will provide another barrier only slightly less formidable.

NOTES FROM OBSERVATORIES

Dominion Observatory, Ottawa, Ontario

Positional Astronomy. C.H.U., the continuous time broadcast, has been equipped with new transmitters on each of the three frequencies, 14670 kc., 7335 kc. and 3330 kc., and new antennas have been constructed for 14670 kc. and 3330 kc. UT2 derived from star observations with the P.Z.T. forms the basis of observatory time. Monthly means, indicating the relation between UT2 and the caesium beam resonator of N.R.C., are published in the time signal correction sheets. A new P.Z.T. observing hut of asbestos siding over a steel framework has been built near the Mirror Transit building. In April, the instrument will be removed from the "temporary" location it has occupied for 8 years. The new Mirror Transit telescope is slowly progressing. Perkin-Elmer successfully reworked the side mirrors of the optical flat which the adhesive had caused to warp. The declination circle, engraved by Hilger and Watts with 7200 divisions, has been installed. Preliminary observations may commence this summer.

Stellar Physics. The staff of the Dominion Radio Astrophysical Observatory, near Penticton, B.C., moved into their new office and control building during the winter. Tests of the 84-foot dish and its receiver have begun, and have included runs on the stronger astronomical radio sources and on the sun. Further progress has been made in the construction of the solar magnetograph at Ottawa. Visual meteor observations by members of the division at Ottawa were discontinued at the close of I.G.C. 1959. The regular meteor programme has continued at the meteor observatories in Alberta, where staff members are also investigating some aspects of the fall of the Bruderheim meteorite on March 4.

Geomagnetism. A three-component airborne survey of the Northwest Territories between latitudes 60°N. and 70°N. was completed during November and December, 1959. Approximately 37,000 line-miles were flown. An analysis has been completed of the amplitude relationships between the magnetic disturbance and earth currents measured at Meanook, Alberta. The conductivity at the bottom of the crust and in the upper mantle has been estimated. Research continues on the morphology of magnetic disturbance in Canada, the horizontal gradients of total field intensity and on the development of different types of proton

precession magnetometers. Further progress has been made in reducing, and preparing for publication, the I.G.Y. magnetic observations from the network of magnetic observatories.

Gravity. In recent years, because of increased field activity in this division, processing, sorting and compilation of data have become a formidable problem. A system has consequently been adopted whereby data from field notes are transferred directly to IBM punch cards. Principal facts for gravity stations are reduced on an electronic computer and the resulting output cards are sorted and listed as required for distribution or for purposes of compilation.

Seismology. Development of the new field equipment and of a three-component seismograph for recording earthquake movements on magnetic tape continued. One of the detectors of the earthquake seismograph is now in preliminary operation. Fault-plane solutions up to the middle of 1957 have now been prepared for publication.

Personnel. Distinguished visitors to the Observatory have included Dr. Robert H. Hardie of Dyer Observatory, Tennessee; Dr. Gerard de Vaucouleurs of Harvard College Observatory, and Drs. Sidney van den Bergh and Donald A. MacRae of the David Dunlap Observatory. The Hon. Paul Comtois, Minister of Mines and Technical Surveys, Dr. Marc Boyer, Deputy Minister and Drs. C. S. Beals and I. Halliday were visitors at the Radio Observatory at Penticton. The D.O. was host to the National Committee for Canada of the I.A.U. last November, and committee members attending represented Canadian Observatories and Universities as well as research institutions where astronomical work is pursued. Some excellent reports were delivered and these appear elsewhere in the JOURNAL. Last fall Mr. R. G. Madill and Dr. E. R. Niblett presented papers at meetings of the Society of Exploration Geophysicists, at Los Angeles, while Mr. M. M. Thomson was the official Canadian delegate to the first Inter-American Astronomical Conference held in Argentina. Early in the new year Dr. K. Whitham returned from a year's leave of absence during which he conducted a geomagnetic survey of British East Africa, under the sponsorship of the United Nations. Drs. C. S. Beals and M. J. S. Innes have recently made a trip to Tennessee in connection with their research on the similarity of certain lunar and terrestrial features. Among recent appointments to the staff are C. H. Costain to the Radio Observatory, L. W. Sobczak to the Gravity Division and L. Dalgetty to Geomagnetism. Dr. Luise Herzberg resigned from the staff to accept an appointment with the Defence Research Board.

MIRIAM S. BURLAND

VARIABLE STAR NOTES

By Margaret W. Mayall

The American Association of Variable Star Observers, Cambridge, Mass.

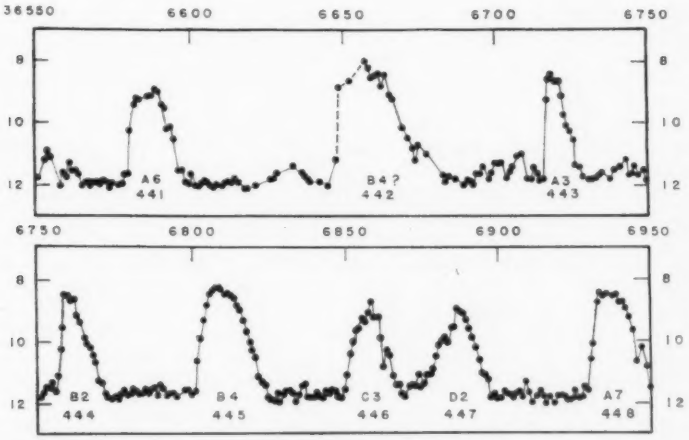
NOTES ON U GEMINORUM-TYPE VARIABLES

213843 *SS Cygni*. During 1959, the star SS Cygni was very well observed and we can be quite certain that no maximum was missed. One maximum (number 442) was well observed on the decreasing branch of the curve, but poorly observed as it increased. The three points which determine the rapidity of the rise, and thus the type of light curve, are of very low weight.

The variable was observed on 313 nights during the year. A total of 1,256 observations was received from 57 observers. This total includes 216 observations made by 9 members of the Scandinavian *Astronomisk Selskab*. Their observations were made available to us through the kindness of the director, Axel V. Nielsen.

The light curve of SS Cygni is a plot of daily means of the observations. The table contains a summary of the characteristics of the 7 maxima observed during 1959. The light curve and table are continuations of those published in these Variable Star Notes each year.

Column 1 of the table gives the number assigned to the maximum. Maxima are numbered consecutively from the first observed maximum in 1896. The second column



Mean light curve of SS Cygni, 1959

1959 MAXIMA OF SS CYGNI

Max. No.	Type	10.0 I J.D.	Diff.	Max. J.D.	Diff.	10.0 D J.D.	Diff.	Max. Mag.
441	A6	2436581	47	2436587	47	2436593	49	9.0
442	B4?	6649?	68?	6656	69	6669	76	8.1
443	A3	6716	67?	6718	62	6723	54	8.5
444	B2	6758	42	6759	41	6766	43	8.5
445	B4	6803	45	6818	59	6828	62	8.3
446	C3	6853	50	6858	40	6862	34	8.8
447	D2	6882	29	6887	29	6892	30	9.0

gives the type of maximum according to Leon Campbell's classification (*Harv. Ann.*, vol. 90, no. 3), which depends on the steepness of the rise and the width of the maximum. Column 3 is the Julian Day when the star is at magnitude 10.0 on the increasing branch of the curve; column 4 is the number of days elapsed since the same point in the preceding epoch; 5, the observed Julian Date of maximum; 6, number of days since the preceding maximum; 7, the Julian Day when the variable is at magnitude 10.0 on the decreasing branch of the curve; 8, days elapsed; and 9, the mean magnitude at maximum.

The mean interval between the maxima of 1959 is 49.6 days. The mean for all maxima of SS Cygni since its discovery is 51.6 days.

Minima of SS Cygni tend to fluctuate, and they were rather brighter than normal during the year. The star barely reached minimum after maximum 446, when it started a slow rise to maximum 447, an almost symmetrical D type.

020356 *UV Persei.* A 13.9 maximum, when UV was brighter than 14 for not more than 4 days, was observed December 8–10 by T. A. Cragg and L. J. Robinson. This is the first maximum observed by the A.A.V.S.O. since 1952.

060547 *SS Aurigae.* Five maxima were observed during the year, and one was probably missed. A complete list of all maxima from the time of discovery in 1907 until 1960, with data giving the characteristics of the curves, was published in *A.A.V.S.O. Bulletin* 22 (Feb. 1960).

061115 *CZ Orionis.* The following maxima were observed: *6587*, 11.8; *6606*, 12.2; *6633*, 12.0; *6663?*, 11.5?; and *6903*, 11.7. Several others had single observations not confirmed.

074922 *U Geminorum.* During 1959, maxima were observed as follows: No. 370, wide, *6650*, 9.2; No. 371, assumed to be narrow, was missed; No. 372 wide?, *6831*, 9.0; and No. 373, narrow, *6908*, 9.6.

080362 *SU Ursae Majoris.* At least 10 maxima were observed during the year; others are doubtful with just one observation. More observations are needed with telescopes that can reach 14th magnitude.

082953 *SW Ursae Majoris.* No maximum brighter than 14.0 has been seen by A.A.V.S.O. observers since Dec. 1943, when it was 10.8 magnitude.

092421 *TU Leonis.* This variable has remained between 13.6 and 14.4 for more than 5 years.

094512 *X Leonis.* A faint variable with frequent maxima, many depending on one or two observations. The following list is a continuation of the one given in these

Notes, Vol. 53, No. 4, p. 195: *6612*, 12.5; *6636*, 12.8; *6672*, 12.1; *6687*, 12.5; *6743*?; *6870*, 12.1?; and *6934*, 12.1.

180514 *UZ Serpentis*. A 12th magnitude maximum was observed by T. A. Cragg on 6834, and a series of observations showed a slow decrease of half a magnitude in 6 days.

184137 *AY Lyrae*. Another faint variable, difficult to observe, with frequent rapid rises. Some of the best observed maxima are: *6726*, 13.2; *6737*, 13.5; *6778*, 13.3; *6801*, 12.6; *6819*, 13.3; *6832*, 13.7; and *6862*?, 13.0. Most of the maxima are very sharp and not more than 2 or 3 days wide at 14th magnitude, but the one at 6801 was well observed and nearly 20 days wide.

184826 *CY Lyrae*. Three maxima observed by Thomas Cragg: *6671*?, 13.8; *6720*, 12.9; and *6867*, 13.3.

195032 *EY Cygni*. No maximum observed.

195109 *UU Aquilae*. Two maxima were observed during 1959; a very narrow one, *6752*, 12.4; and a very wide one, *6804*, 11.4.

203501 *AE Aquarii*. This star varies so rapidly that single observations are of little value, unless they are very accurately timed. During a fine series of runs of closely spaced observations, Leif Robinson observed the following maxima: *6753*, 10.5; *6758*, 10.7; and *6762*, 10.7. Many other runs by Robinson and others showed variations of about half a magnitude.

220912 *RU Pegasi*. The following maxima were observed: *6706*, 10.5; *6753*?, 11.5; *6779*, 10.3; and *6833*?, 11.5.

A.A.V.S.O. Nova Search Report (from George Diedrich, Chairman): Observations of Nova Search Areas were made by the following 29 observers for a total of 512 area-nights reported. Each name is followed by the number of observations made in November and then December, 1959: R. Bishop—12, 7; B. Brown—20, 16; F. J. DeKinder—18, 26; D. Diedrich—2, 5; G. Diedrich—7, 10; C. L. Drolet—9, 11; P. Evans—14, 0; K. Fuller—15, 11; G. Gaherty, Jr.—4, 6; B. Green—0, 4; D. Matthies—0, 1; H. C. Nightingale—0, 16; W. L. Isherwood, Jr.—22, 26; D. W. Orchiston—24, 21; C. G. Phillips—30, 38; R. Prezament—3, 3; R. T. Price—1, 0; B. Reber—3, 4; D. Sands—5, 0; G. W. Smith—5, 0; G. A. Spencer—9, 1; F. Traynor—10, 11; R. Venor—2, 0; R. Walk—0, 5; W. A. Warren—6, 0; G. Wedge—0, 1; I. K. Williamson—9, 6; R. Zit—20, 0; K. Zorgo—14, 24.

Special Note. At last we have another bright nova. A cable from Dr. J. Vinter Hansen at Copenhagen reports the discovery by Hassel in Norway of a 5th magnitude nova near the border of Aquila and Hercules. The announcement read: U. T. $4^h\ 30^m$ March 7, 1960, Mag. 5, $\alpha\ 18^h\ 51^m$ (1855), $\delta\ +13°00'$. An observation was received from Leonard Solomon as follows: U. T. $9^h\ 20^m$, March 16, mag. 5.6. We hope it remains bright for some time.

Observations received during January and February 1960: A total of 7,442 observations was received for the two months: 3,602 from 65 observers in January, and 3,840 from 73 observers in February.

Observer	January		February	
	Var.	Ests.	Var.	Ests.
Adams, R. M.	87	151	90	157
Ahnert, P.	14	118	..	..
Allin, R.	30	30	..	..
Anderson, C. E.	81	158	10	10
Anderson, E.	..	..	4	4
Beidler, H. B.	6	6	..	..
Berg, J.	56	186	51	68
Bicknell, R. H.	12	36	17	68
Brady, R. F.	15	15	12	16
Braune, W.	..	..	20	153
Breckinridge, J.	..	..	1	1
Brinley, F. J.	3	5	2	2
Carlisle, J. H.	1	2	..	..
Cragg, T. A.	109	114	112	137
Crotty, J.	..	..	10	10
Darsenius, G.	..	..	9	15
de Kock, R. P.	146	577	103	444
Diedrich, D.	4	4	3	3
Diedrich, G.	7	11	2	2
Dudley, R. R.	..	..	15	30
Engelkemeir, D.	13	28	13	24
Erpenstein, O. M.	12	20	7	7
Evans, P.	14	31	11	64
Farmer, R.	3	3	..	..
Fernald, C. F.	260	439	206	372
Fletcher, D. M.	..	..	4	6
Ford, C. B.	48	50	65	67
Frogel, J. A.	3	3	2	3
Fuller, K.	..	..	36	36
Godfrey, N. B.	33	34	36	36
Goodsell, J. G.	..	..	2	2
Graham, J.	..	..	4	4
Grossenbacher, R.	..	..	5	5
Halbach, E. A.	..	..	32	40
Hartmann, F.	157	182	149	156
Hull, A.	1	1	3	4
Hurless, C.	..	..	1	1
Hutchings, N. O.	..	..	13	13
Judd, D.	12	12	19	19
Kaminski, W. J.	6	9	3	3
Kelly, F. J.	9	10	15	22
Kindt, O. H.	11	11	..	..
Knowles, J. H.	9	14	8	11
Lacchini, G. B.	23	63	..	..
Lattey, M.	13	14	..	..
Lowder, W. M.	16	16	26	26
Lynch, J. S.	..	..	1	1
Matthies, D.	1	1	..	..
McPherson, C. A.	16	16	10	10
Miller, R. W.	..	..	16	46
Miller, W. A.	7	7	4	4
Montague, A. C.	14	14	15	16
Morgan, F. P.	..	..	21	33
Muniz, L.	8	9	8	9
Nightingale, H. C.	..	..	4	18
Olmsted, M.	1	2	..	..
Oravec, E. G.	202	414	237	447
Orchiston, D. W.	30	91	46	138
Peltier, L. C.	17	47	17	50
Price, R. T.	2	3	7	23
Quester, W.	..	..	4	10
Renner, C. J.	48	48	..	..
Ries, J.	1	1	2	2
Rizzo, P. V.	15	22	6	6
Robinson, J. C.	38	44	4	5
Robinson, L. J.	2	2	1	1
Rosalsky, R.	..	..	1	1
Rosebrugh, D. W.	17	68	17	110
Rudolph, R.	..	..	30	163
Schiff, S.	4	6	..	..
Sealy, R. N.	5	8	..	..
Sharpless, A. P.	14	14	12	12
Shinkfield, R. C.	8	10	10	20
Smith, J. R.	7	7	10	13
Solomon, L.	3	3	..	..
Staer, R. R.	2	2	..	..
Stanton, R.	19	19	17	18
Taboada, D.	94	104	134	235
Templeton, J. H.	9	9	5	5
Thomas, M. A.	..	..	2	4
Traynor, F.	5	15	14	33
Tsai, C. H.	..	..	36	93
Valdez, M.	14	14	..	..
Van Til, A.	1	1	..	..
van Zyl, L. L.	40	75	23	38
Williamson, L. J. A.	..	..	3	8
Williamson, P. L.	1	1	4	20
Wilson, C. F.	8	8	32	32
Wyckoff, J.	..	..	22	41
Yamada, T.	43	164	34	134

Vol. 54, No. 3 JUNE 1960 Whole No. 444

Some Topics in Molecular Astronomy ..... *Andrew McKellar* 97
Elements of Astromechanics *(to be continued)* ..... *Peter van de Kamp* 110

CANADIAN SCIENTISTS REPORT–XXII
Astronomy in Canada *(concluded)* 126

ANNUAL MEETING AND GENERAL ASSEMBLY OF THE R.A.S.C.
Minutes of Annual Meeting at Toronto 140
Report of Meeting at Montreal 141
New Honorary Members 142
New Service Awards 142
National Officers and Council for 1960 143

REVIEW OF PUBLICATIONS
Extensive Air Showers by William Galbraith; *Astronomy* by Theodore G. Mehlin; *Contemporary Physics: A journal of interpretation and review*; *Russian-English Glossary of Optics and Spectroscopy* edited by I. Emin... 144

NOTES FROM OBSERVATORIES ..... *Miriam S. Burland* 149
VARIABLE STAR NOTES ..... *Margaret W. Mayall* 147

EDITOR—Ruth J. Northcott ASSISTANT EDITOR—Leonard Searle

ASSOCIATE EDITORS—C. S. Beals, R. M. Petrie, A. Thomson

COMMUNICATIONS TO THE EDITORS SHOULD BE ADDRESSED TO

David Dunlap Observatory, Richmond Hill, Ontario

The Society publishes this JOURNAL bi-monthly (February, April, June, August, October and December) and the OBSERVER'S HANDBOOK annually. Single copies of either of these publications are 75 cents.

Membership, which includes the publications, is open to anyone interested in astronomy. Annual dues are $5.00; life membership is $75.00. Application for membership or publications should be made to THE ROYAL ASTRONOMICAL SOCIETY OF CANADA, 252 COLLEGE STREET, TORONTO 2B, ONTARIO.